Los Alamos
NATIONAL LABORATORY
EST. 1943

LA-UR-21-20605
Approved for public release; distribution is unlimited.

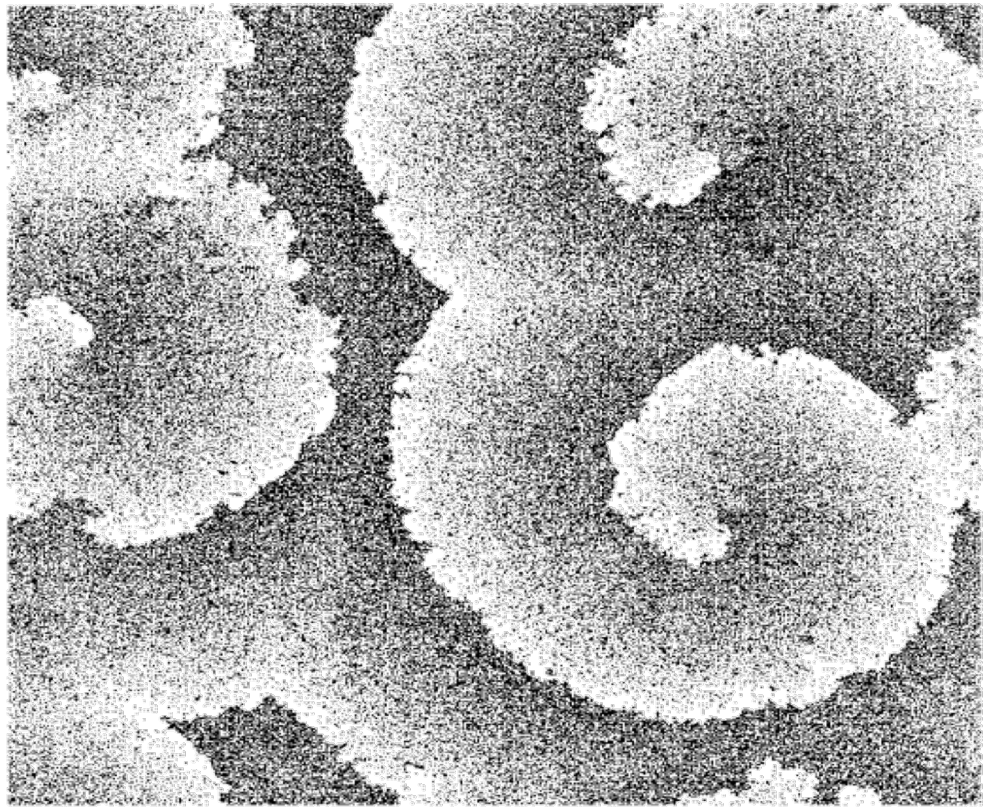
Title: Sensitivity of modeled fire behavior to small perturbations in initial conditions

Author(s): Jonko, Alexandra
Yedinak, Kara
Conley, Juliana
Linn, Rodman Ray
Atchley, Adam Lee
Parsons, Russell

Intended for: University Seminar at Montana State University, Computer Science Department, January 25, 2021

Issued: 2021-01-25

Disclaimer:
Los Alamos National Laboratory, an affirmative action/equal opportunity employer, is operated by Triad National Security, LLC for the National Nuclear Security Administration of U.S. Department of Energy under contract 89233218CNA000001. By approving this article, the publisher recognizes that the U.S. Government retains nonexclusive, royalty-free license to publish or reproduce the published form of this contribution, or to allow others to do so, for U.S. Government purposes. Los Alamos National Laboratory requests that the publisher identify this article as work performed under the auspices of the U.S. Department of Energy. Los Alamos National Laboratory strongly supports academic freedom and a researcher's right to publish; as an institution, however, the Laboratory does not endorse the viewpoint of a publication or guarantee its technical correctness.



Sensitivity of modeled fire behavior to small perturbations in initial conditions

Alex Jonko[1], Kara Yedinak[2], Juliana Conley[1], Rod Linn[1], Adam Atchley[1], and Russ Parsons[3]

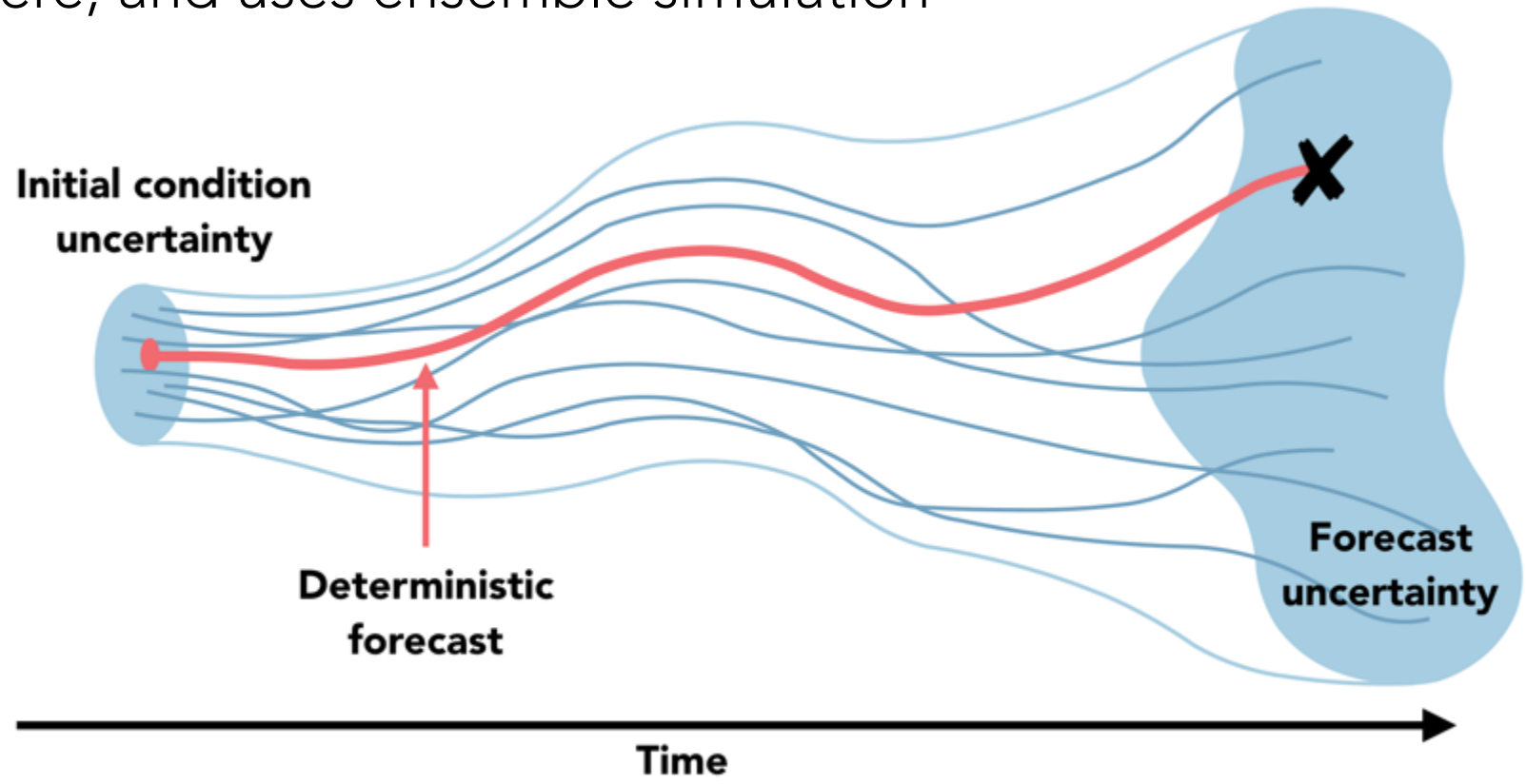
[1] Computational Earth Science Group, Los Alamos National Laboratory
[2] Forest Products Laboratory, US Forest Service
[3] Rocky Mountain Research Station, US Forest Service

Los Alamos NATIONAL LABORATORY EST. 1943

FOREST SERVICE US DEPARTMENT OF AGRICULTURE

Chaotic systems: strong sensitivity to small perturbation

Weather forecasting acknowledges chaotic nature of atmosphere, and uses ensemble simulation

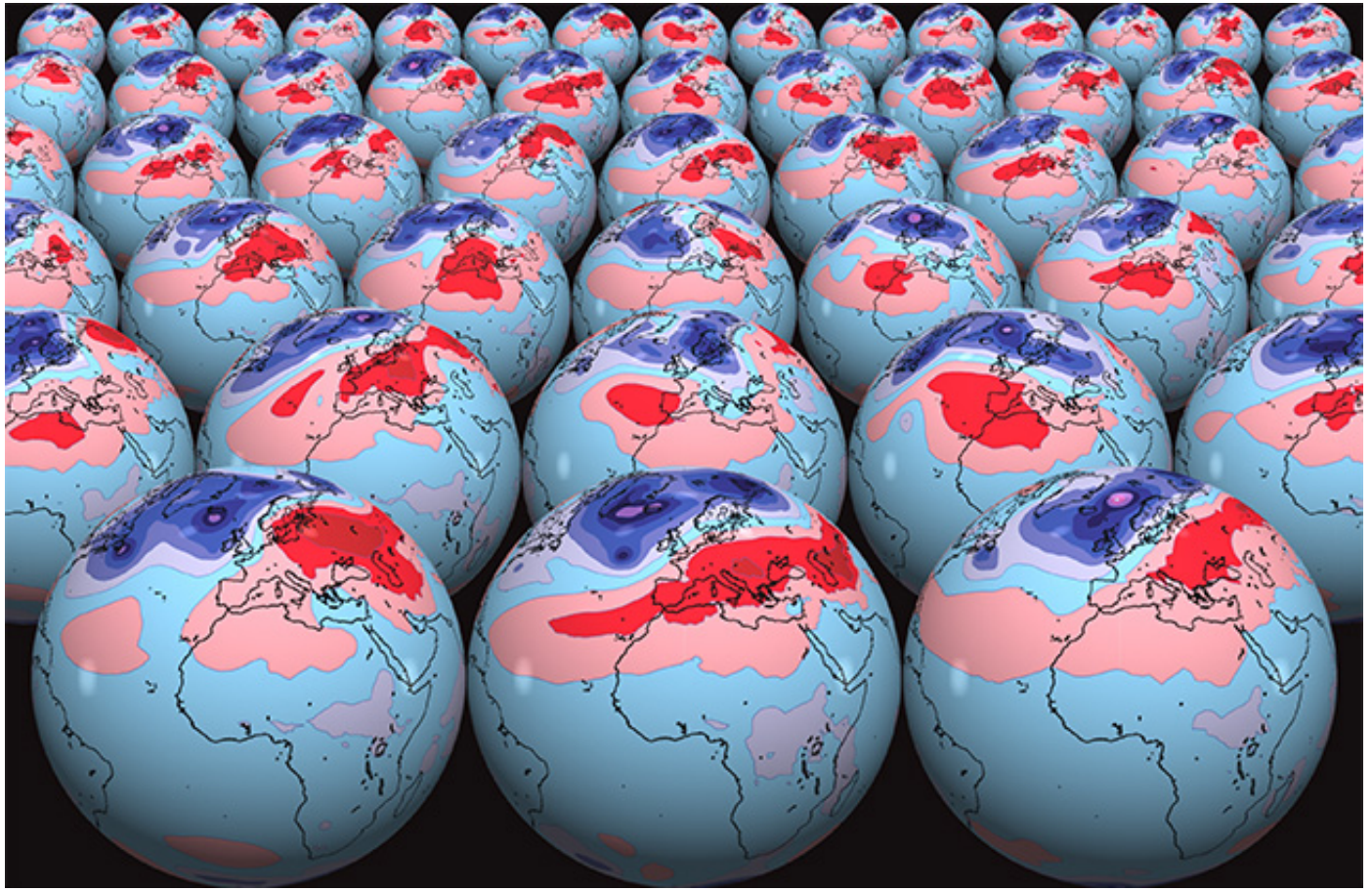


Chaotic systems: strong sensitivity to small perturbation

European Centre for Medium-Range Weather Forecasts example forecast of temperature anomalies over Europe:

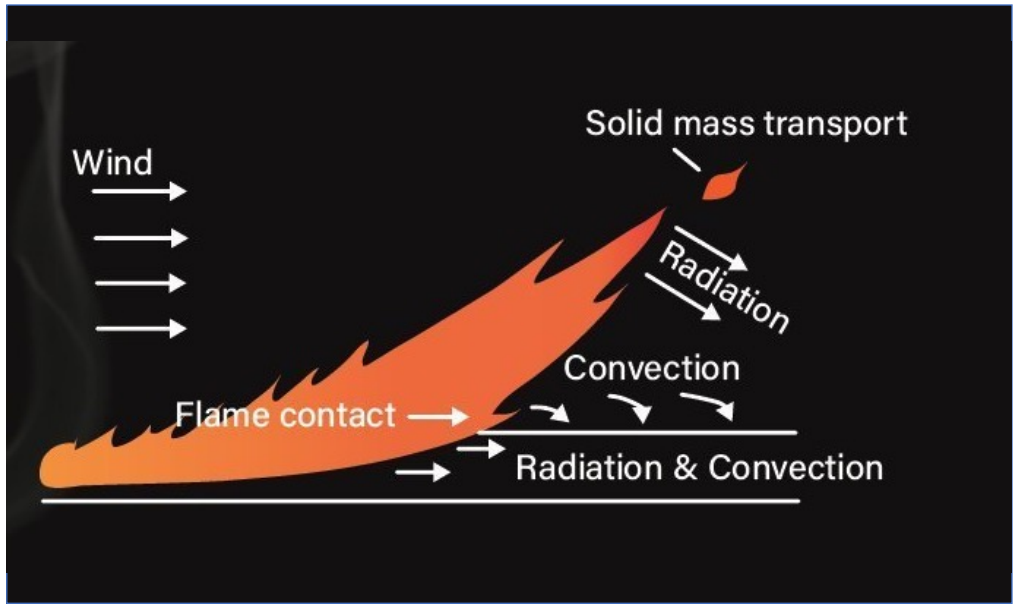
~50 members are used for each forecast

Should we be doing the same for wildfire?



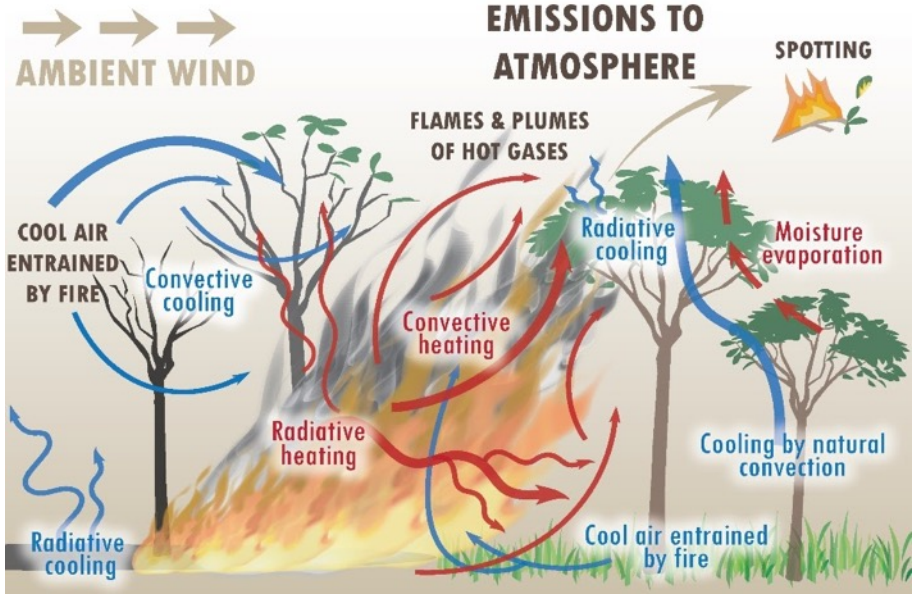
The spectrum of fire models

empirical models
(e.g. Rothermel)



Fast, simplified, operationally used

"physics-based" models
(e.g. FIRETEC)

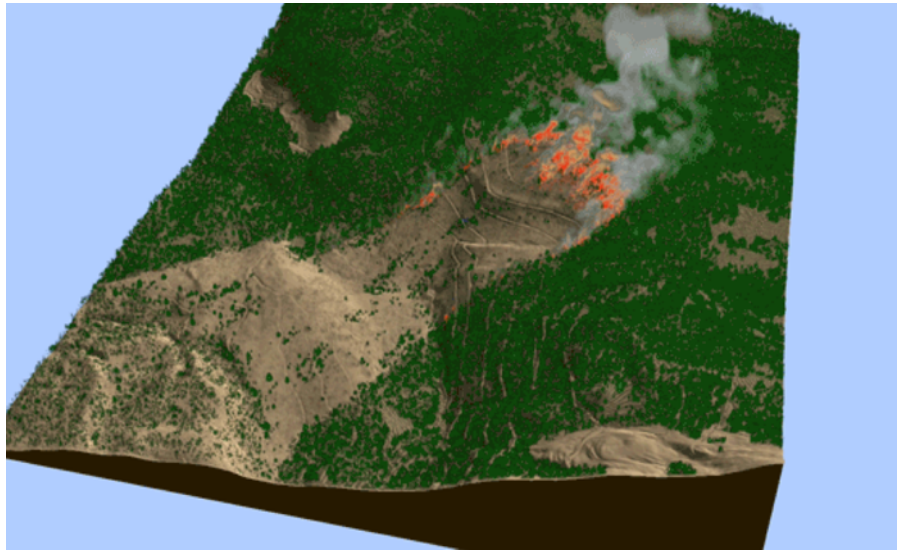


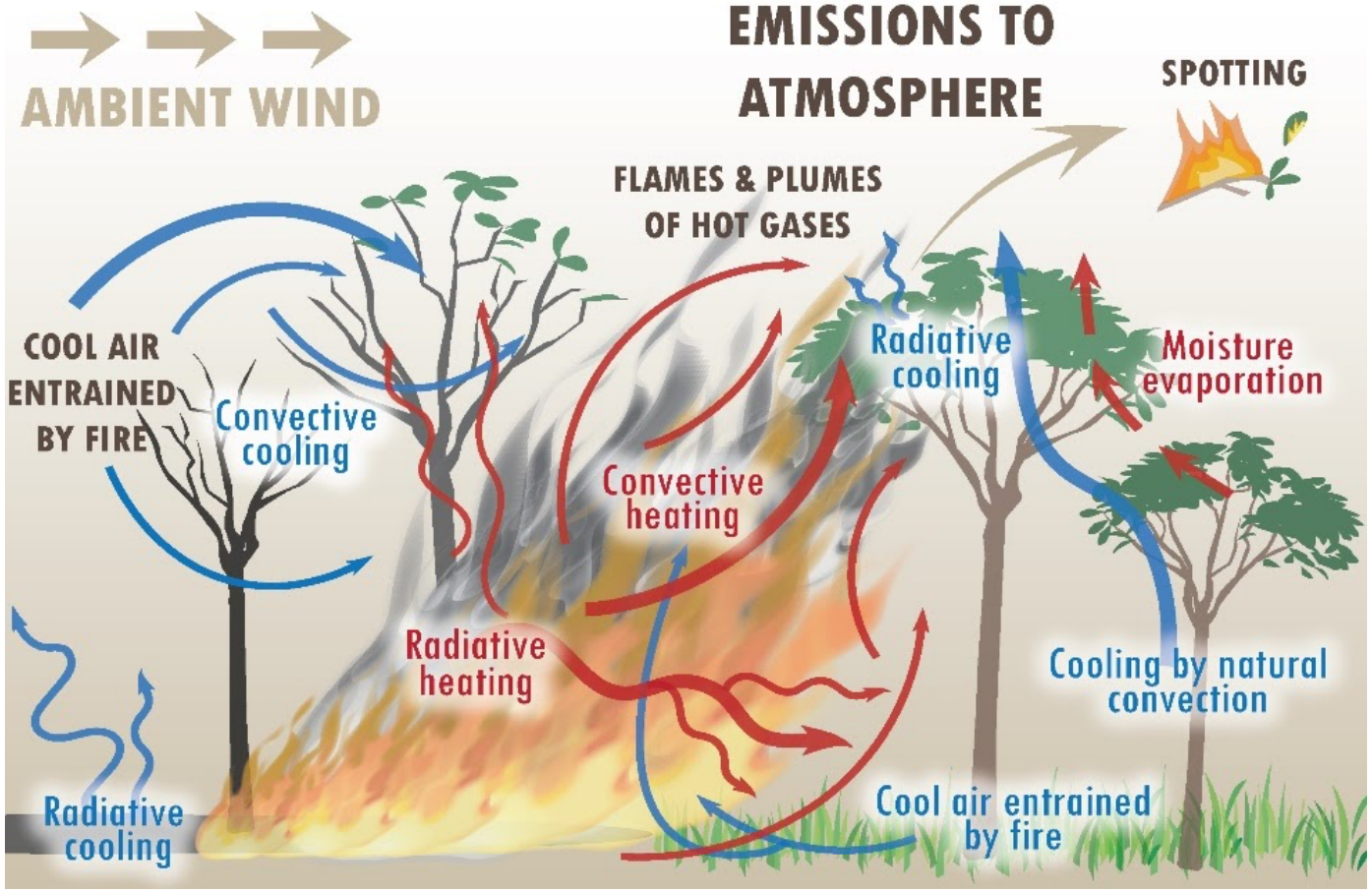
Detailed, computationally expensive, used in research

HIGRAD/FIRETEC: coupled fire-atmosphere modeling

HIGRAD/FIRETEC:

- HIgh GRADient hydrodynamic model of atmospheric flow
- combustion and heat transfer model
- Discrete fuel beds at meter resolution

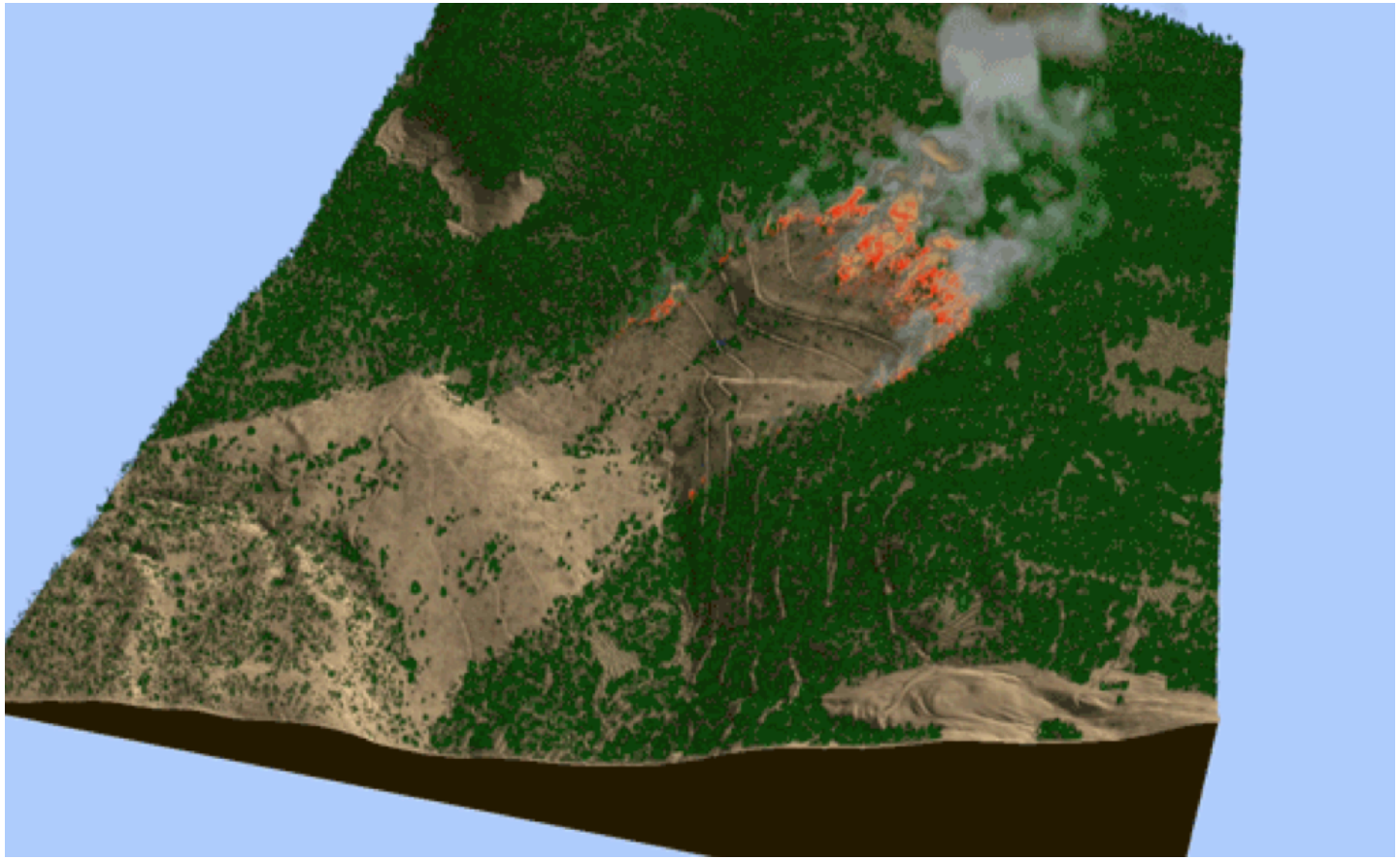




HIGRAD/FIRETEC: coupled fire-atmosphere modeling

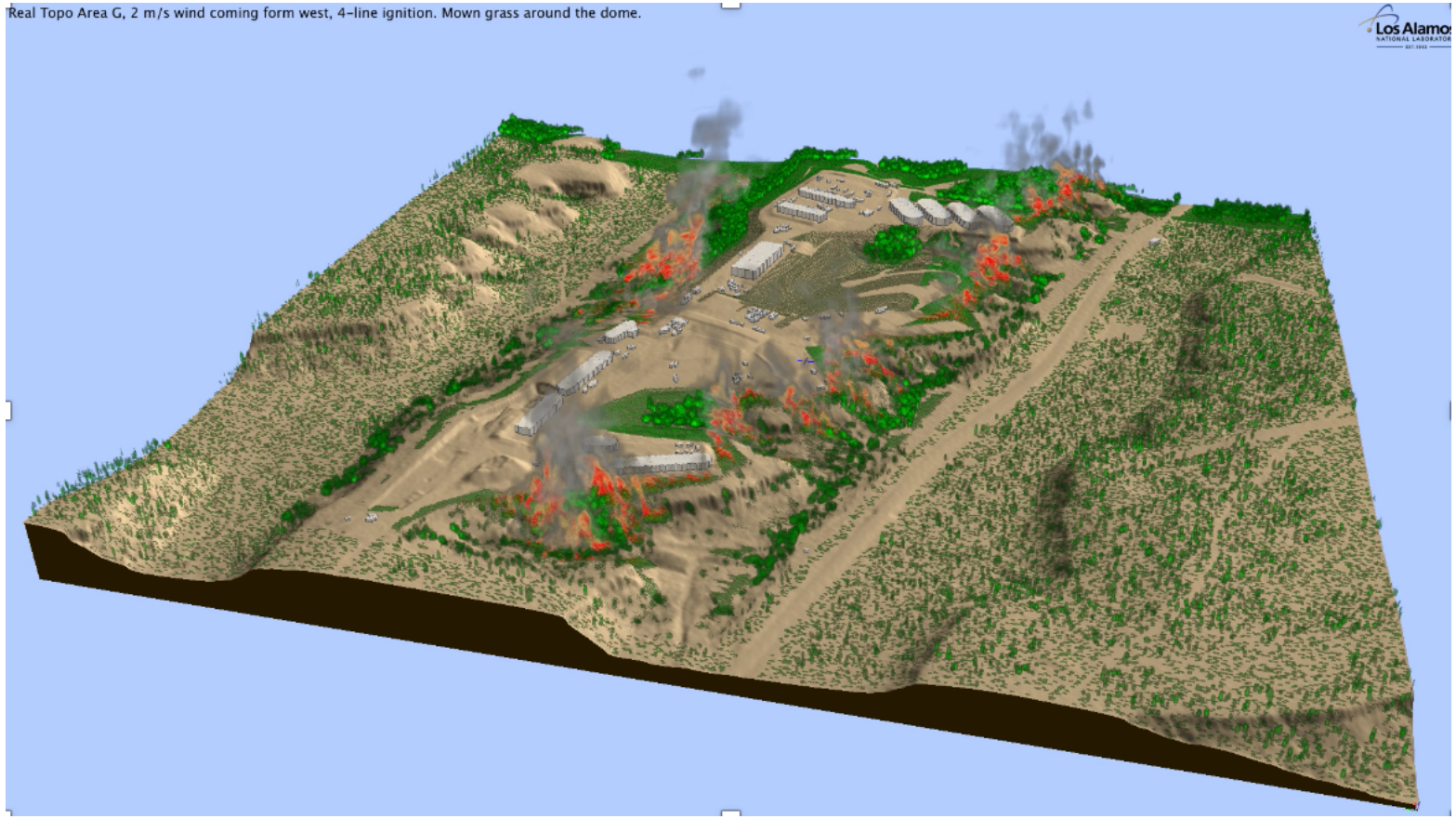
- Research tool that can be used for simplified simulations of certain aspects of fire behavior, or portions of real wildfires

Movie removed for RASSTI



HIGRAD/FIRETEC: coupled fire-atmosphere modeling

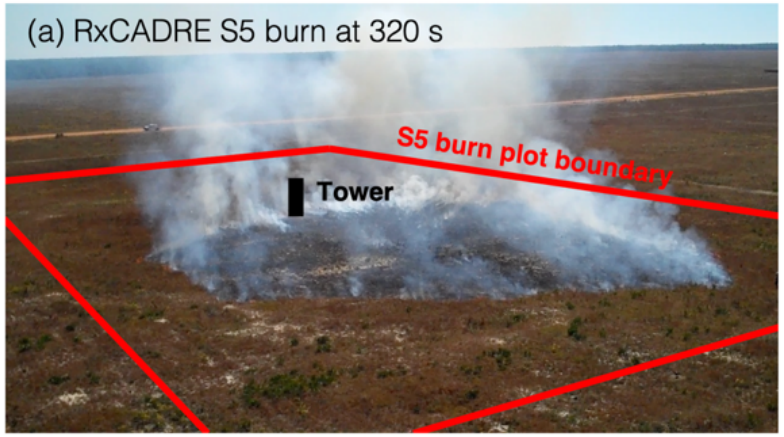
- Research tool that can be used for simplified simulations of certain aspects of fire behavior, or portions of real wildfires
- Has been used to inform prescribed fire planning
- Internal application: evaluate fire risk to LANL infrastructure

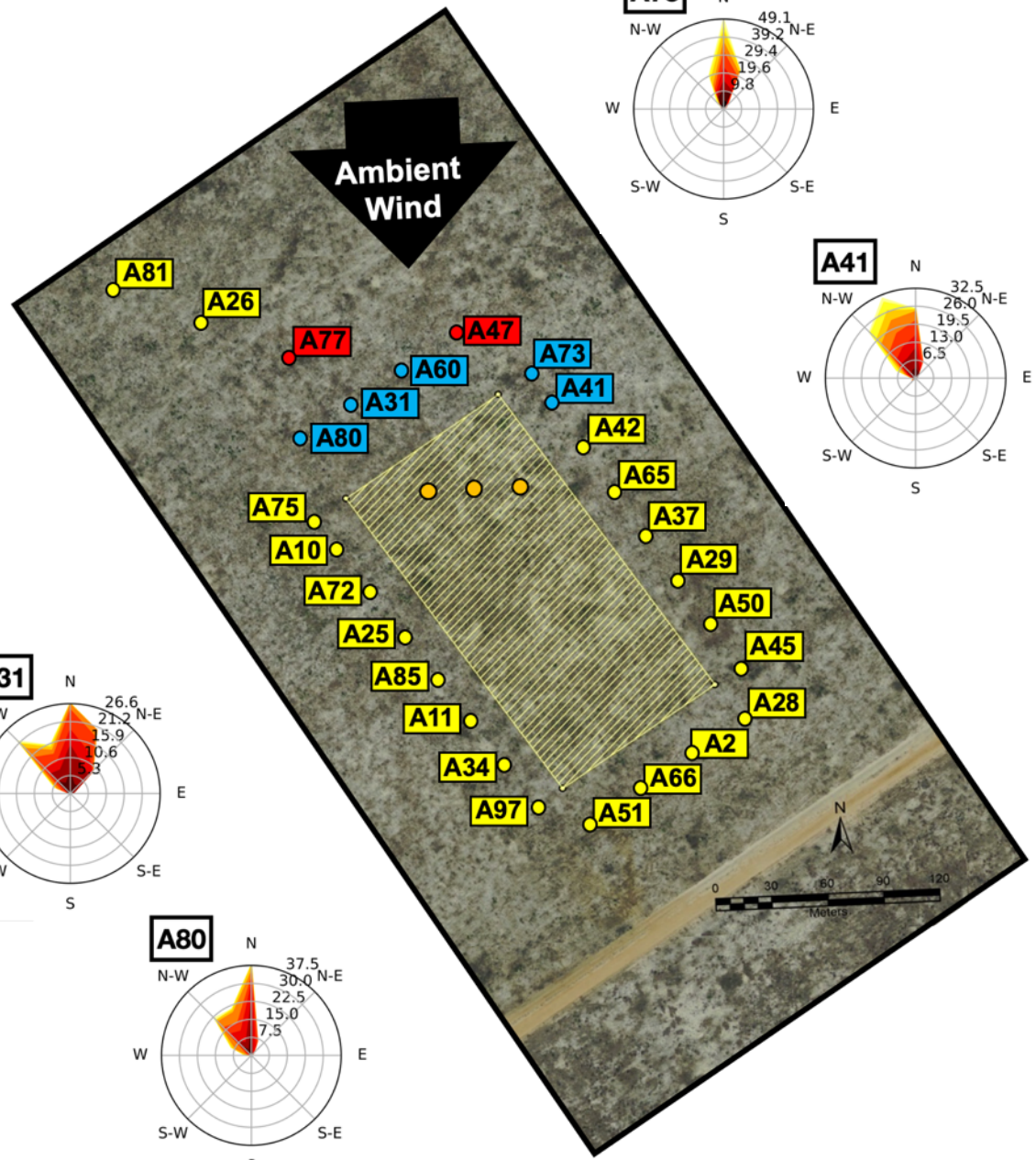


Movie removed for RASSTI

Are fires chaotic systems?

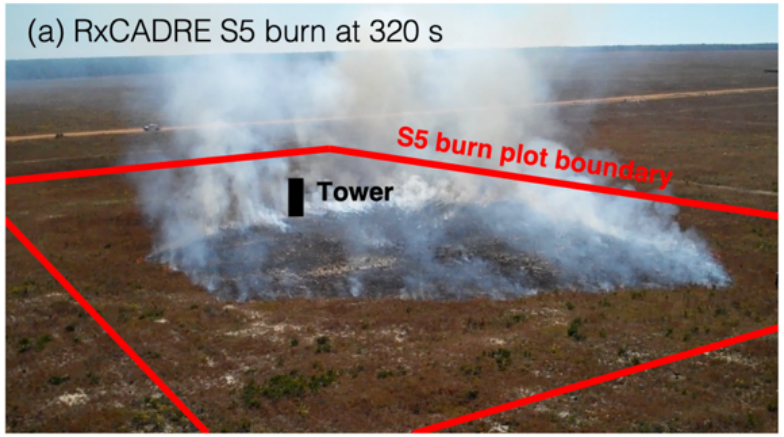
FIRETEC simulations of the RxCADRE fire experiment, using data from adjacent anemometers, show strong sensitivity of fire to perturbations in the turbulent wind field



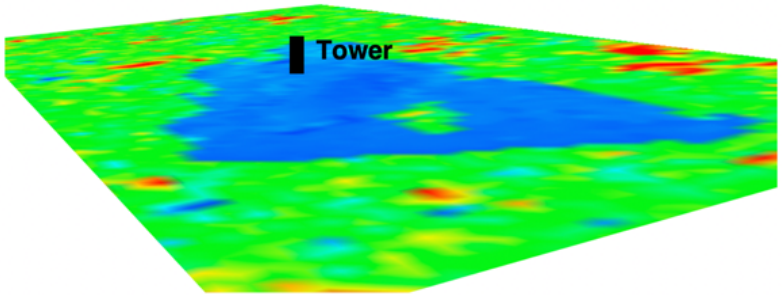


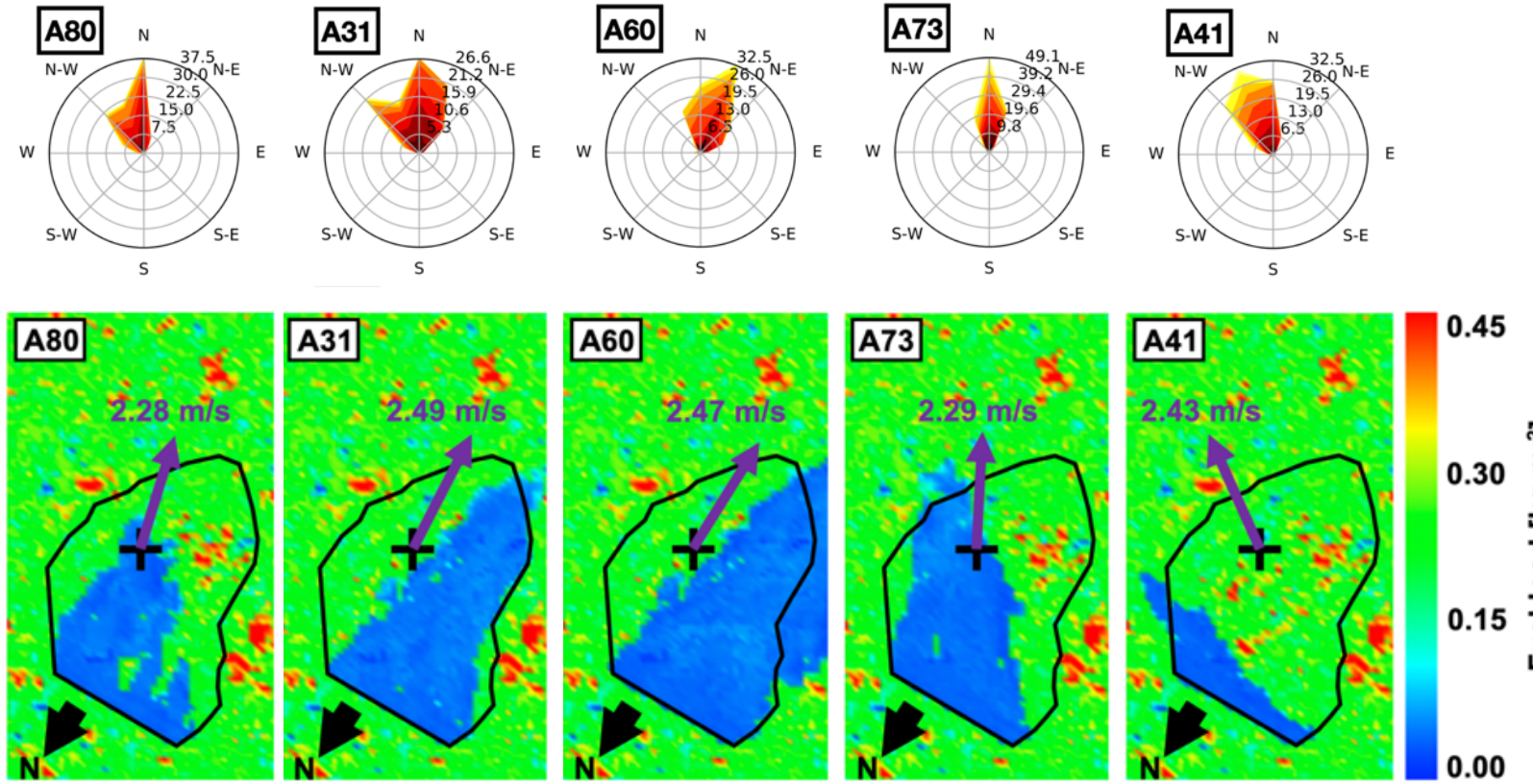
Are fires chaotic systems?

FIRETEC simulations of the RxCADRE fire experiment, using data from adjacent anemometers, show strong sensitivity of fire to perturbations in the turbulent wind field



(b) FIRETEC simulation of S5 burn at 320 s





Linn, R. et al. (2021) Modeling Low Intensity Fire: Lessons Learned from 2012 RxCADRE. MDPI Atmosphere (in press).

Study Design

1. Sensitivity to perturbations in atmospheric initial conditions

Image credit: Tall Grass Prairie National Preserve

Fuels: homogenous grass

Winds: log profile: 2.5 m/s at 10 m

Vary:
- location of ignition within turbulent wind field
- fuel moisture

2. Sensitivity to perturbations in initial conditions of fuels

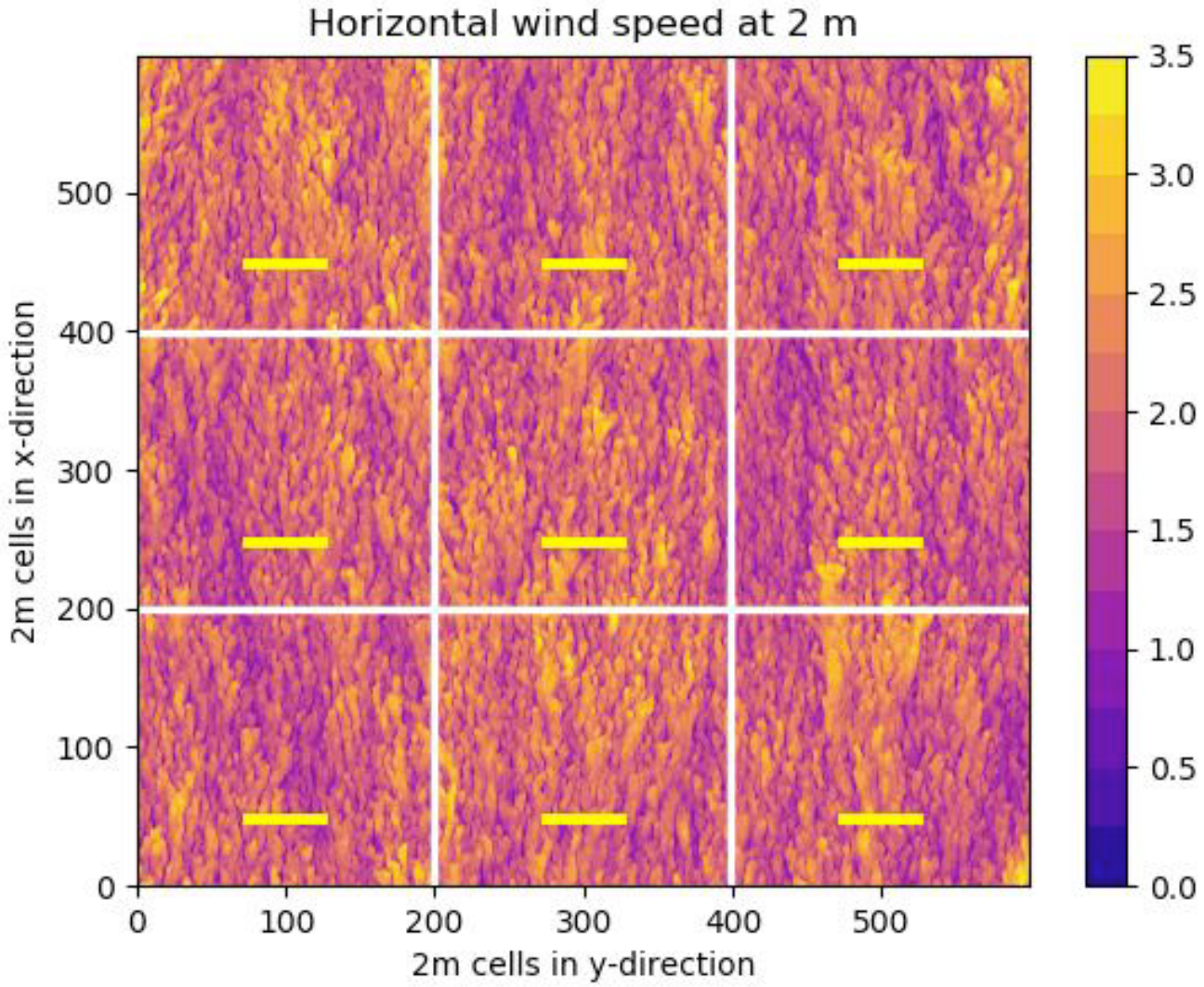
Image credit: Coconino National Forest

heterogenous Ponderosa Pine stands

log profile: 6.5 m/s at 25 m

- level of aggregation of trees
- location of ignition in heterogeneous fuel beds
- timing of ignition in turbulent wind field

1. Spin up a large turbulent wind field

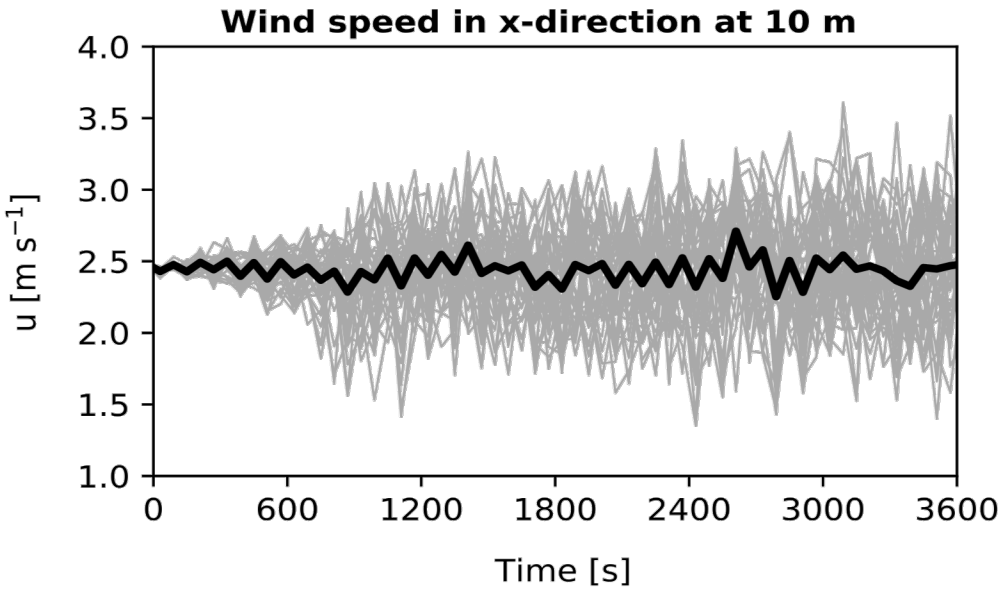


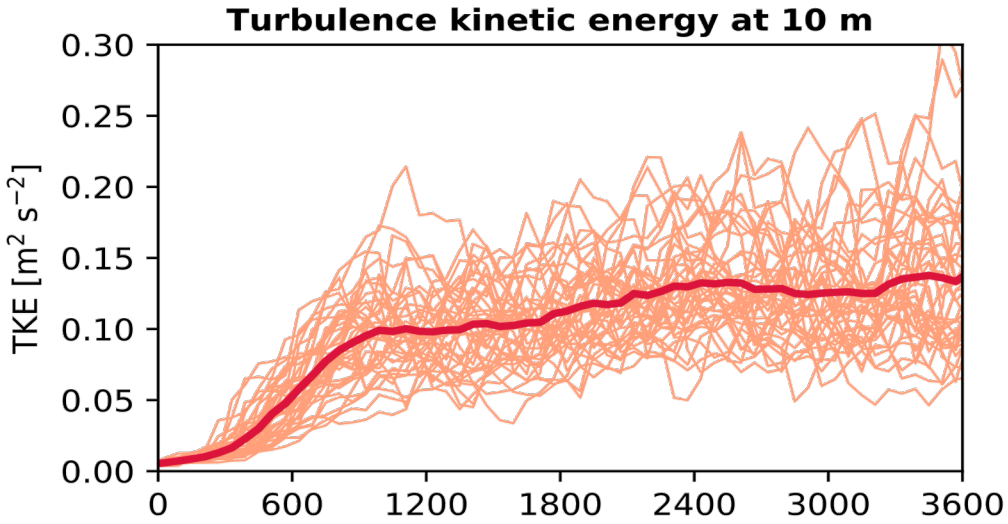
- Turbulent wind spin up on large (1200 m x 1200 m) domain
- 9 small (400 m x 400 m) domains nested within for fire runs

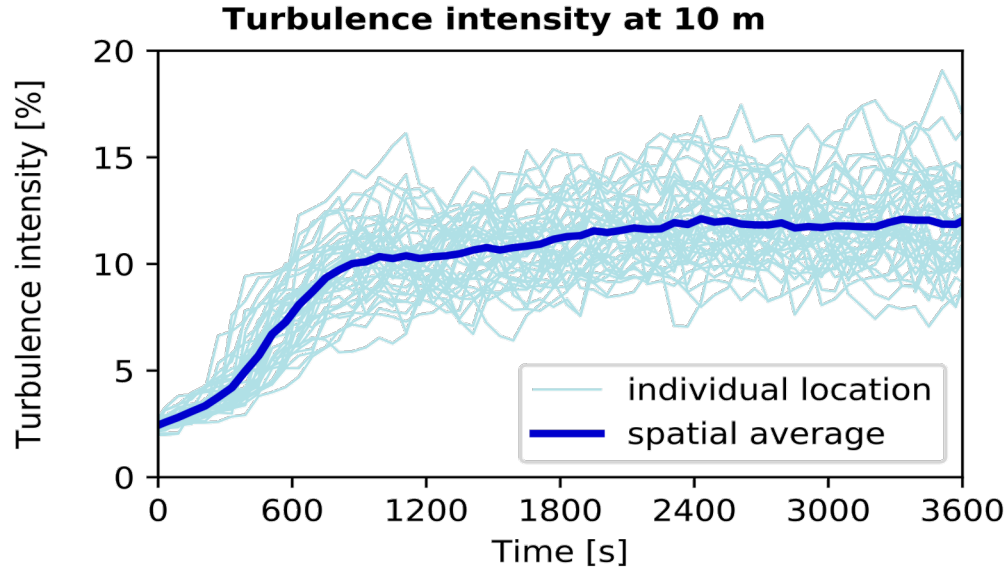
Movie:

- 2 m horizontal wind speed across large domain
- small domain boundaries and ignition lines added for reference

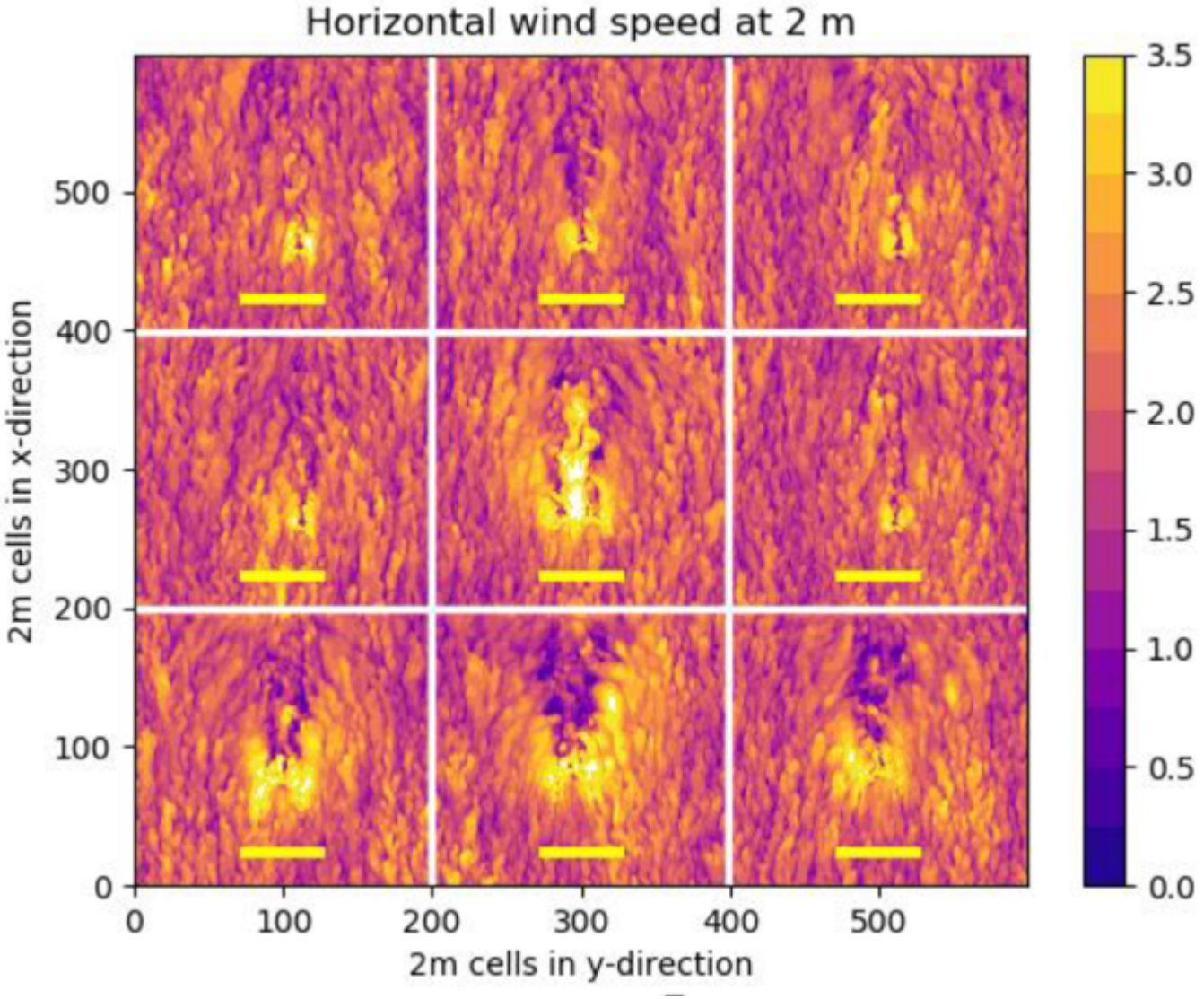
1. Spin up a large turbulent wind field





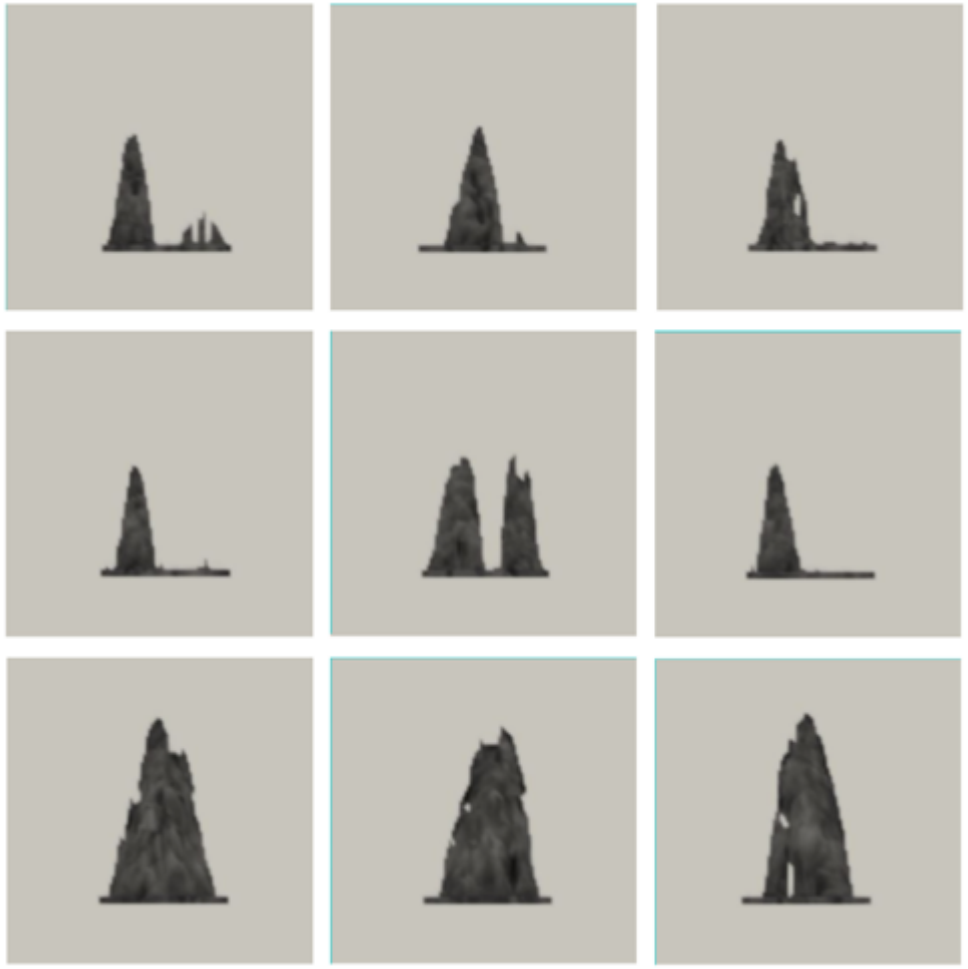


2. Ignite fires in each of the 9 small domains



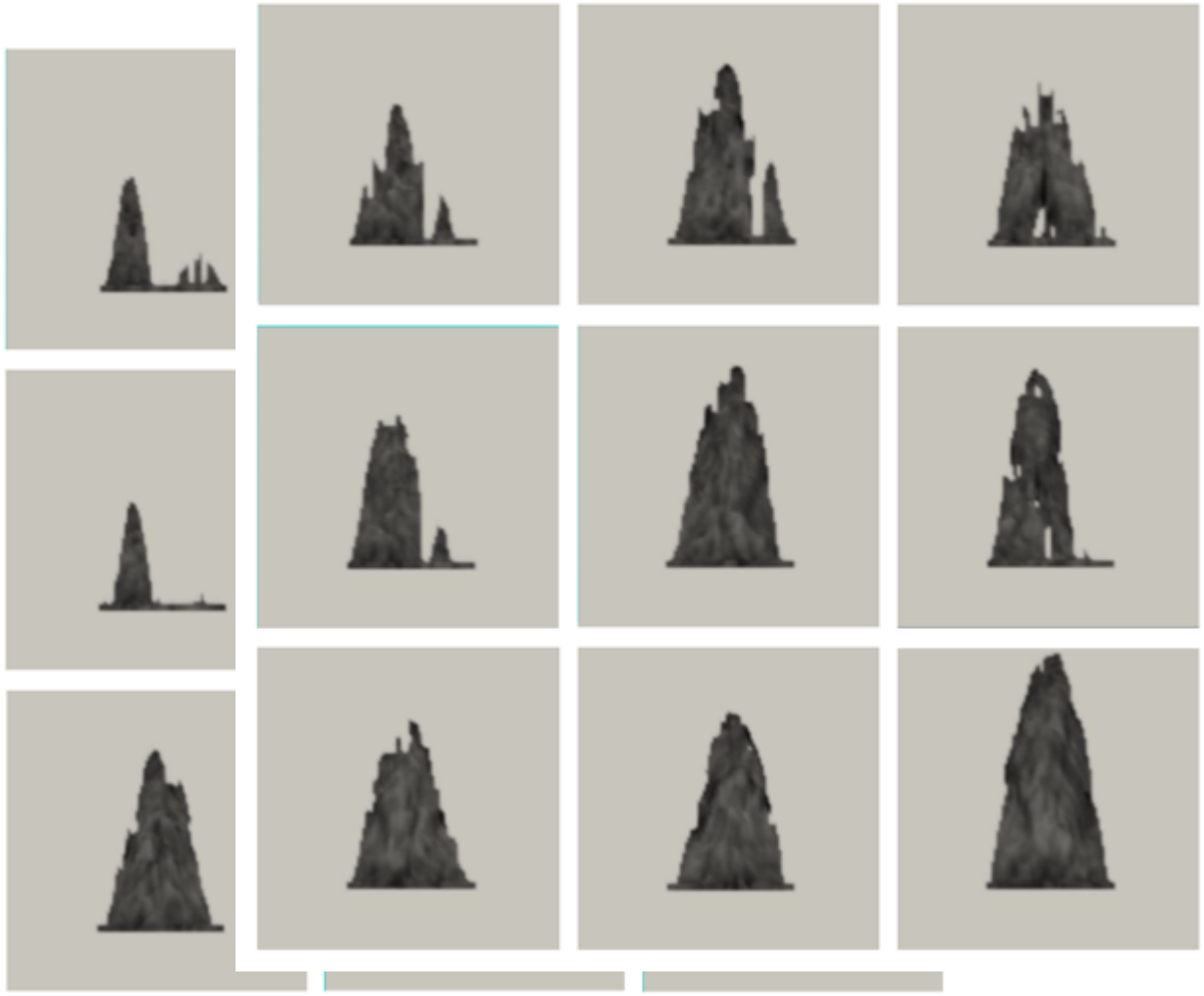
- Winds in each small domain do not interact with winds in neighboring domains.
- Fire in one domain is independent of the others.

3. Examine fire outcomes: Area burned



- Final fire scars from the first 9 simulations highlight variability.
- Next, we run 9 more fires in the same domains, moving ignition forward in time by 60 seconds.
- Since fuels are homogenous, we consider location and timing of ignition as interchangeable.

3. **Examine fire outcomes:** Area burned

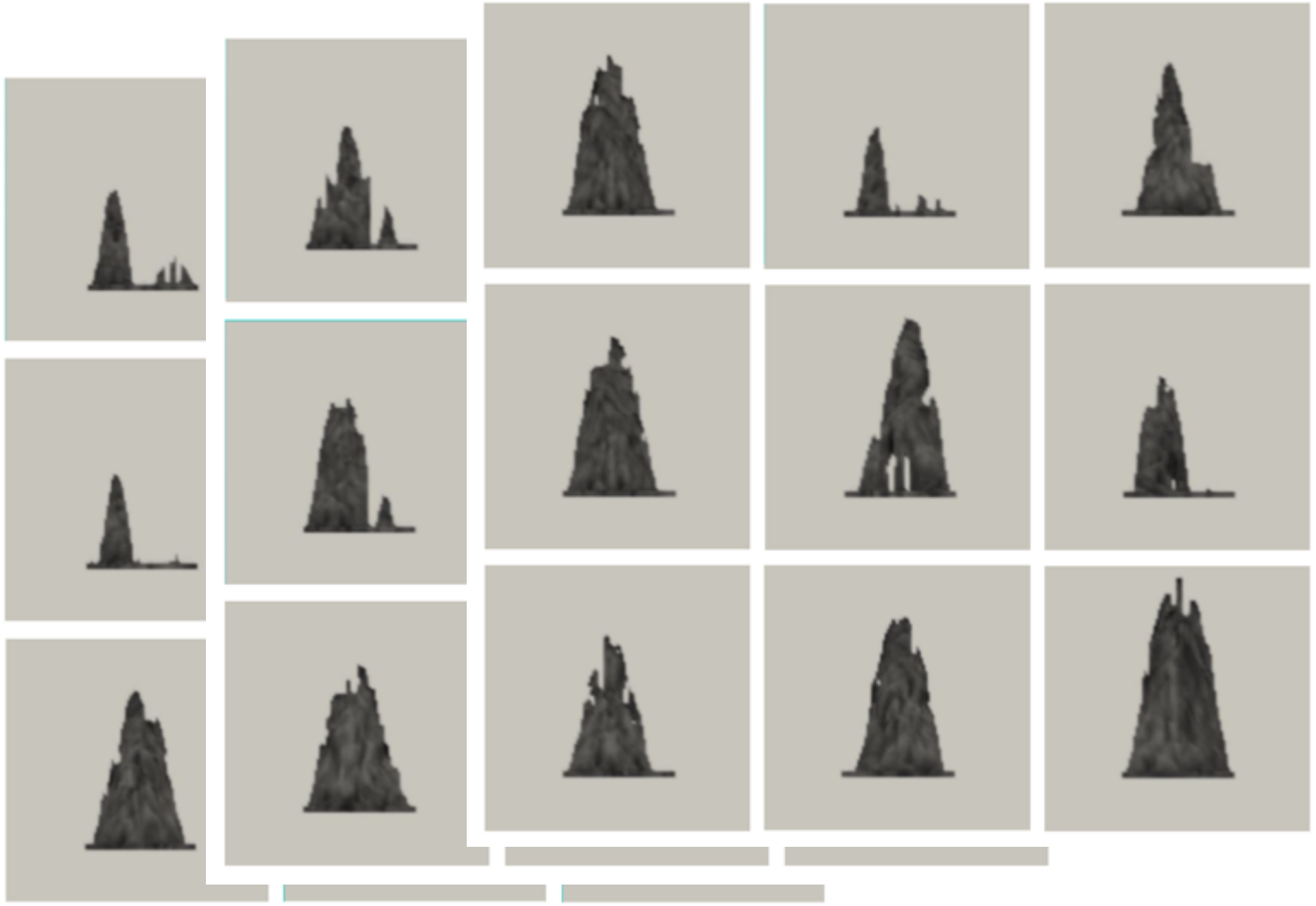


al fire scars from the first 9
ulations highlight variability.

xt, we run 9 more fires in the
ne domains, moving ignition
ward in time by 60 seconds.

ce fuels are homogenous, we
nsider location and timing of
ition as interchangeable.

3. Examine fire outcomes: Area burned

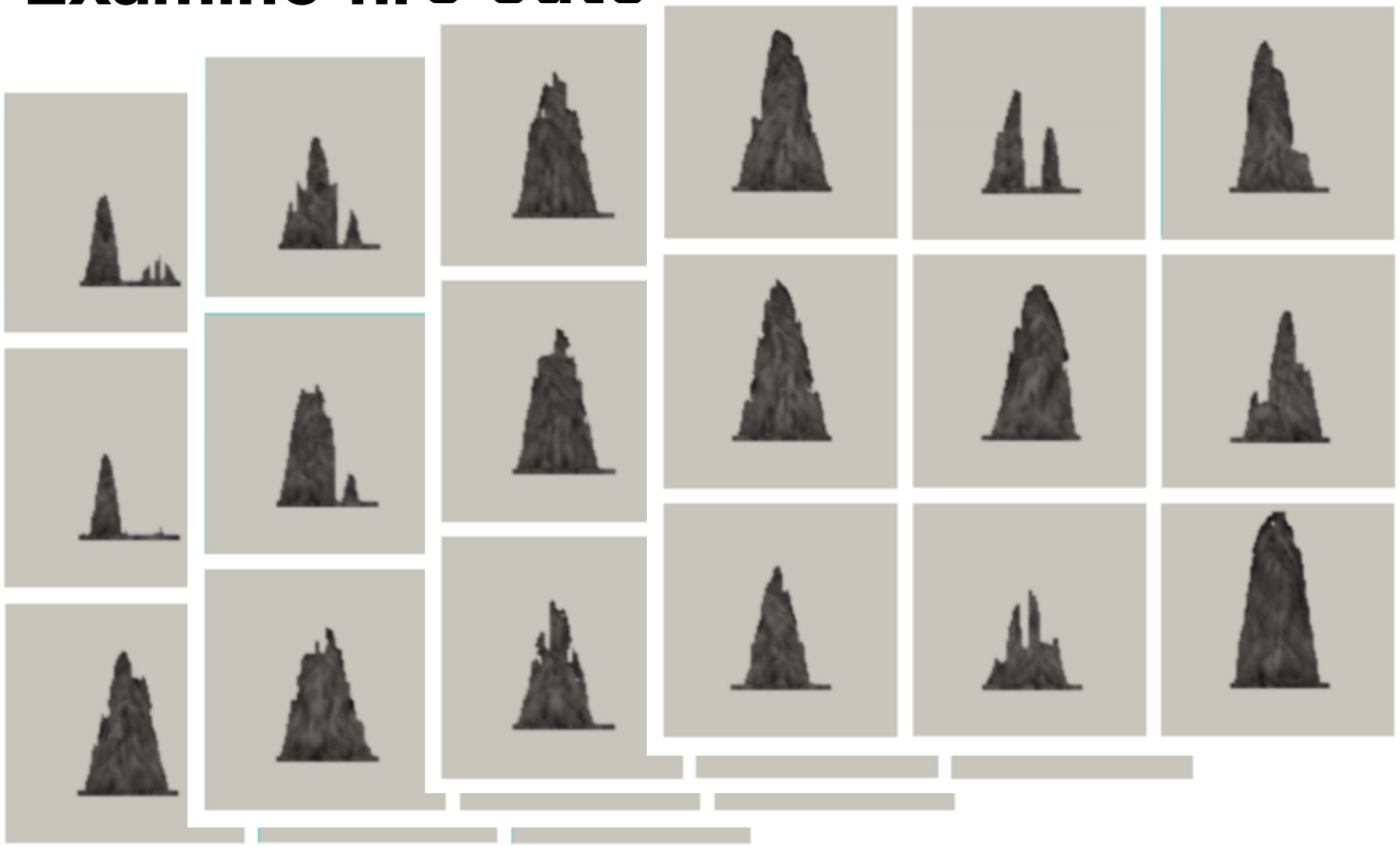


om the first 9
light variability.

nore fires in the
moving ignition
by 60 seconds.

omogenous, we
n and timing of
changeable.

3. Examine fire outcomes: Area burned

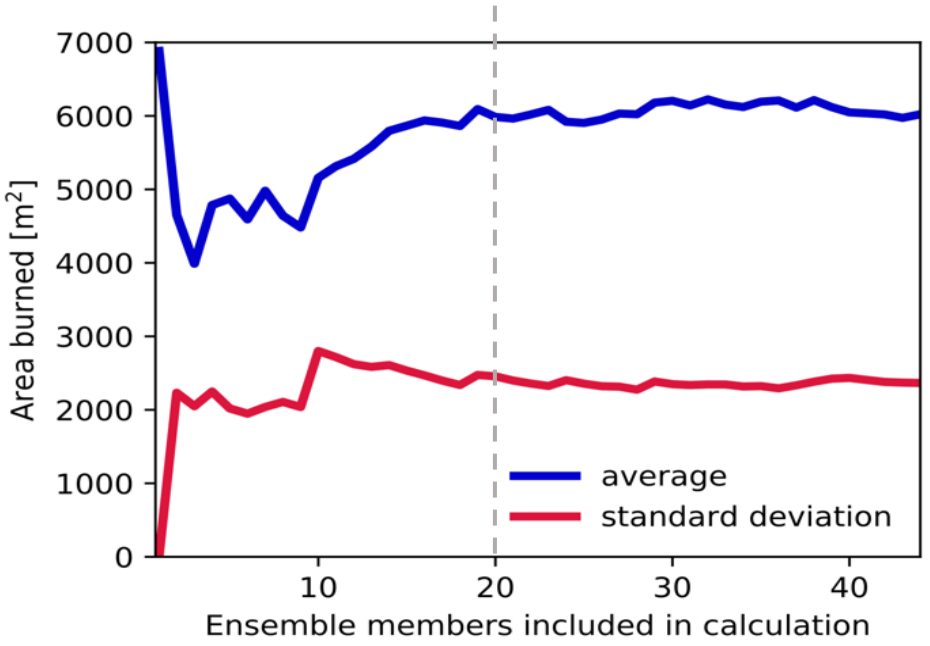


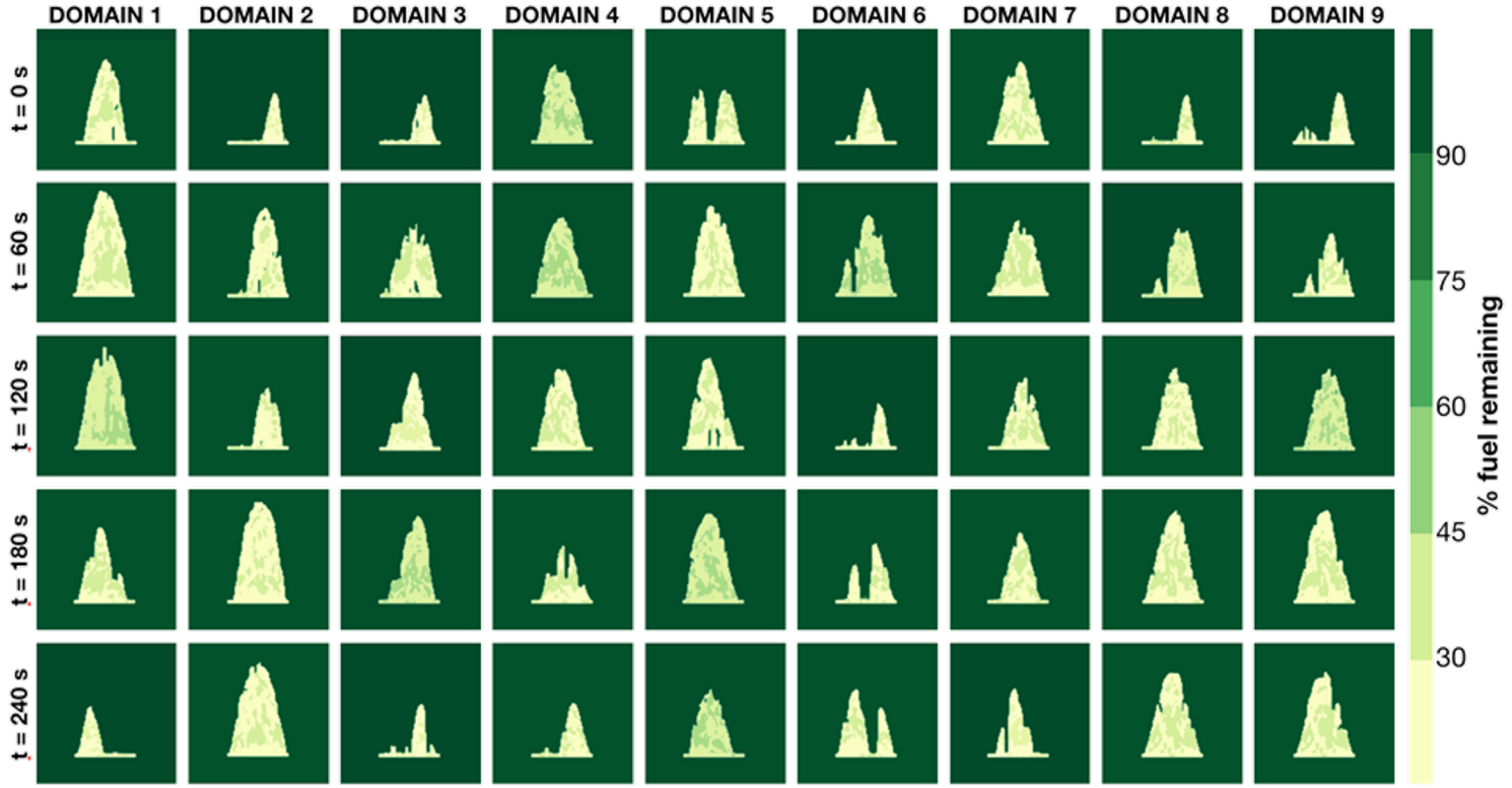
t 9
ility.

n the
ition
nds.

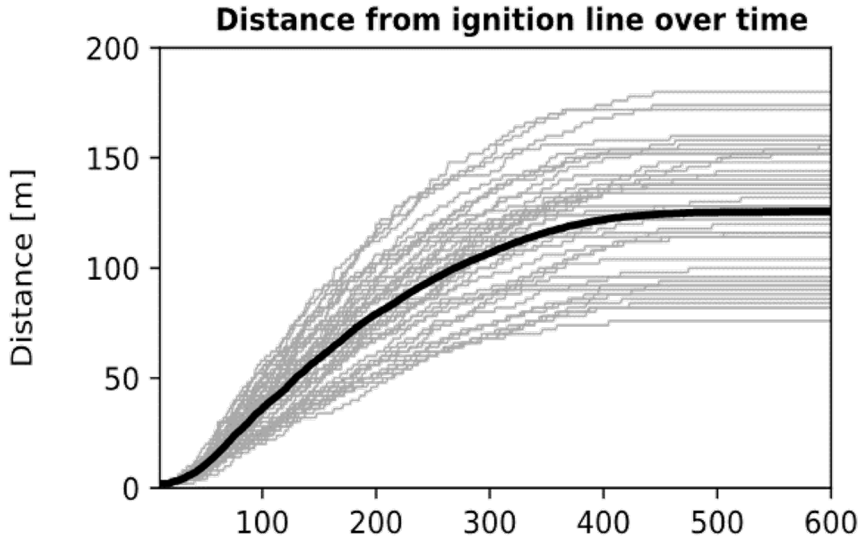
us, we
ng of
e.

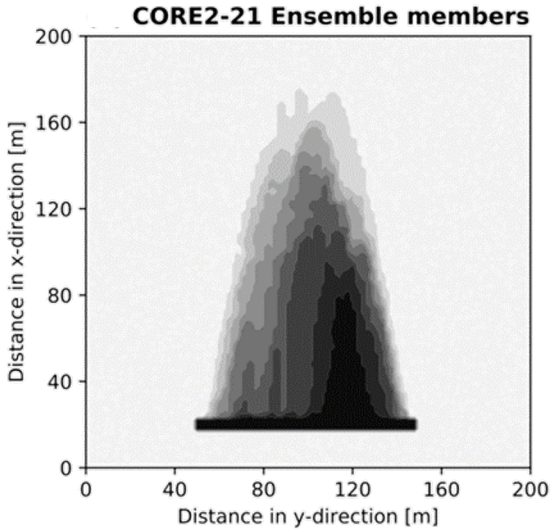
3. Examine fire outcomes: Area burned

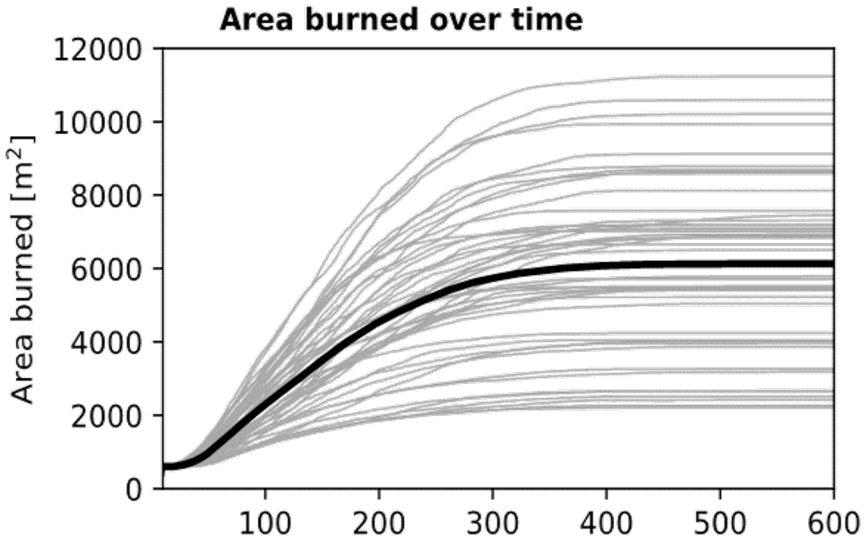


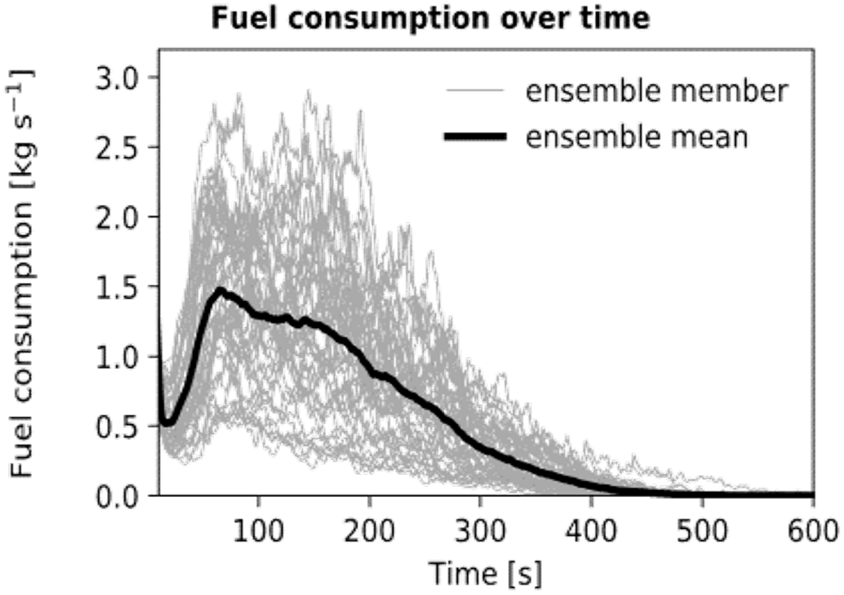


3. Examine fire outcomes: Clustering and diverging behavior



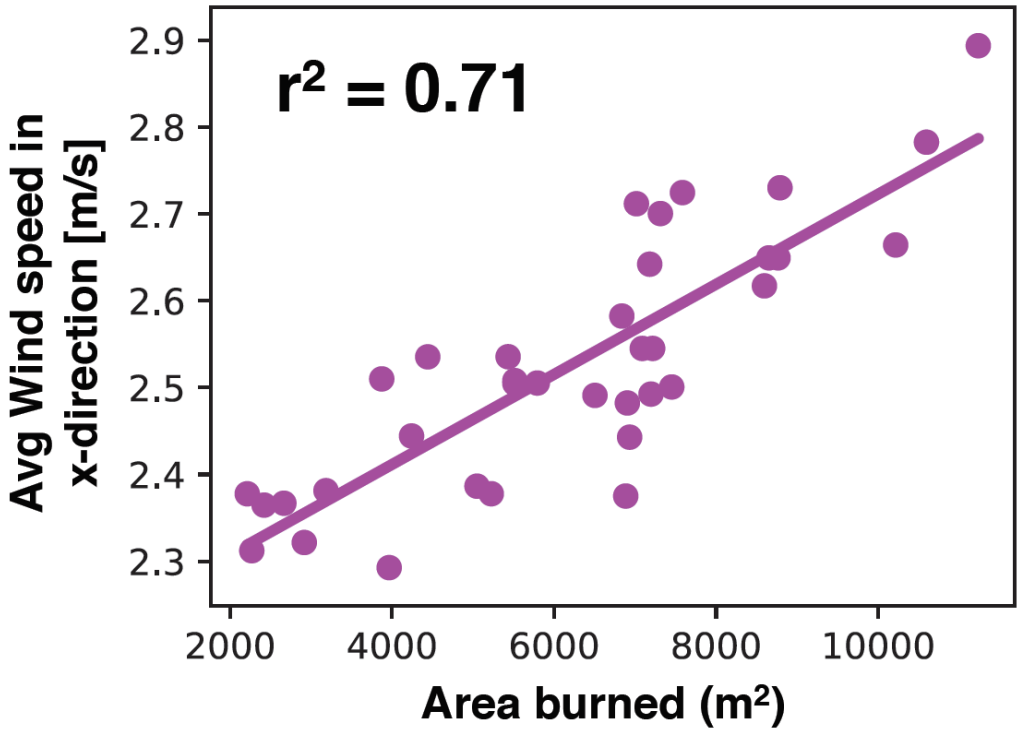




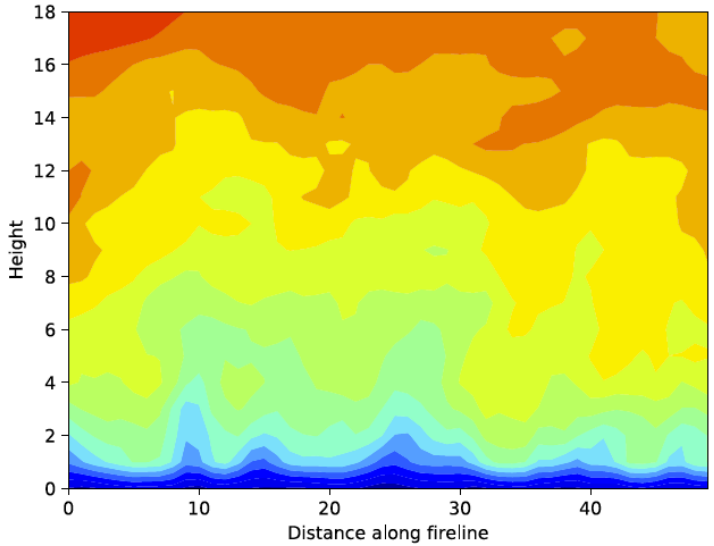


3. Examine fire outcomes:

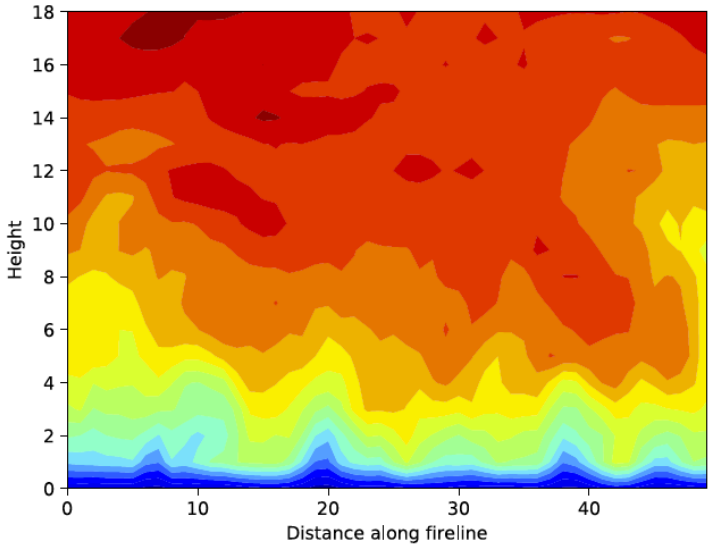
Impacts of wind at time of ignition



The smallest fire in the ensemble is associated with low mean winds in x direction at the inlet

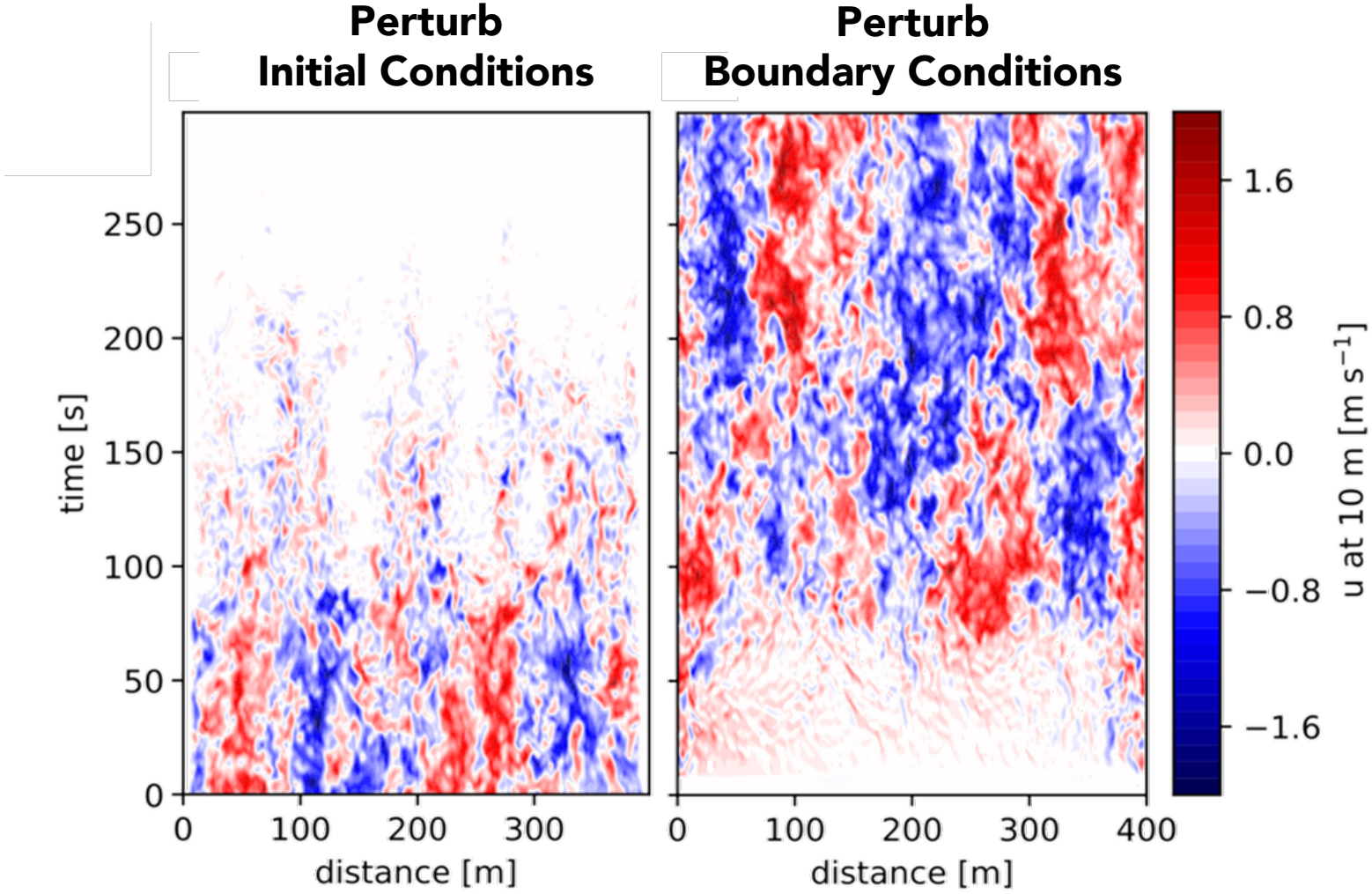


The largest fire in the ensemble is associated with high mean winds in x direction at the inlet



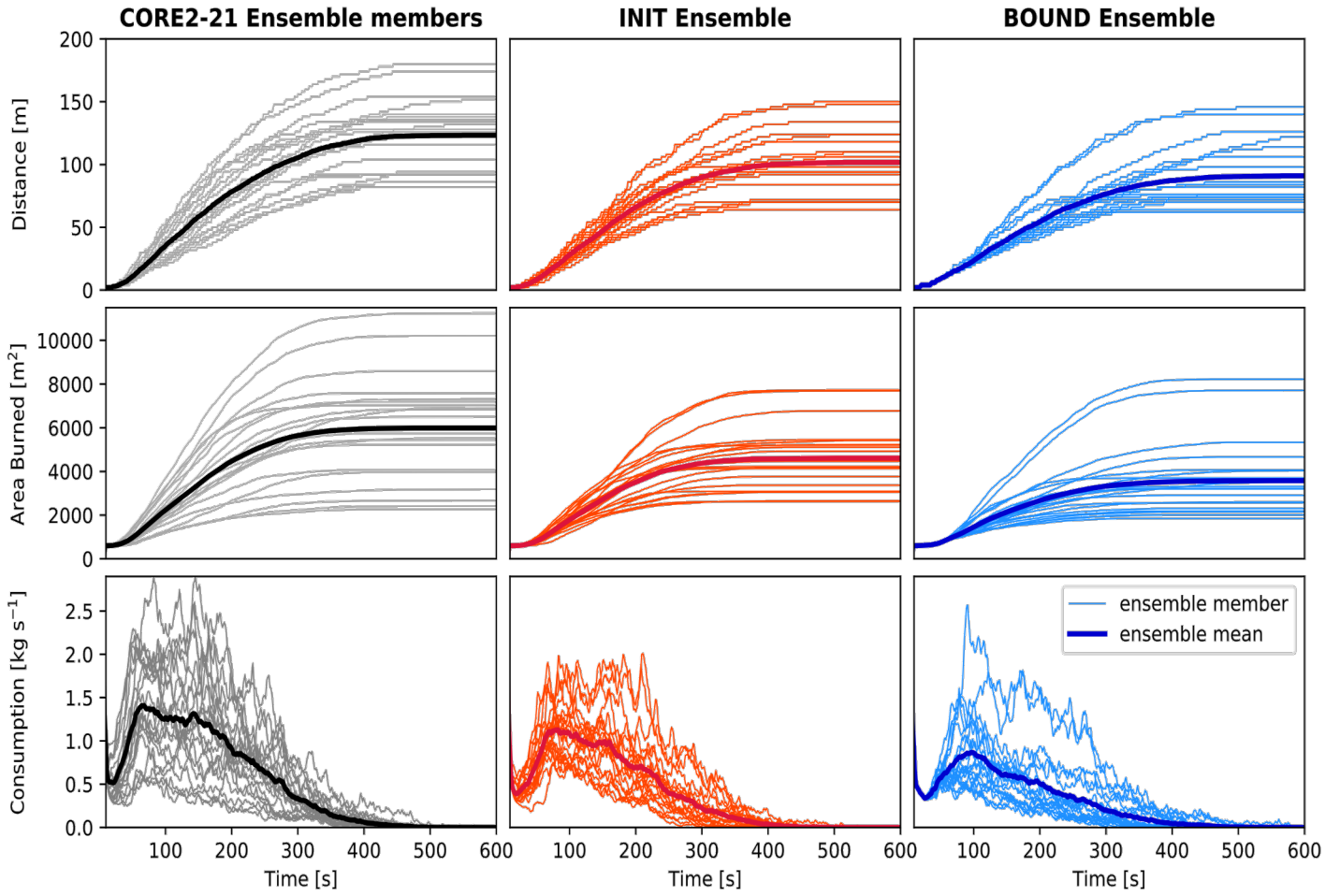
3. Examine fire outcomes:

Impacts of wind boundary vs initial conditions

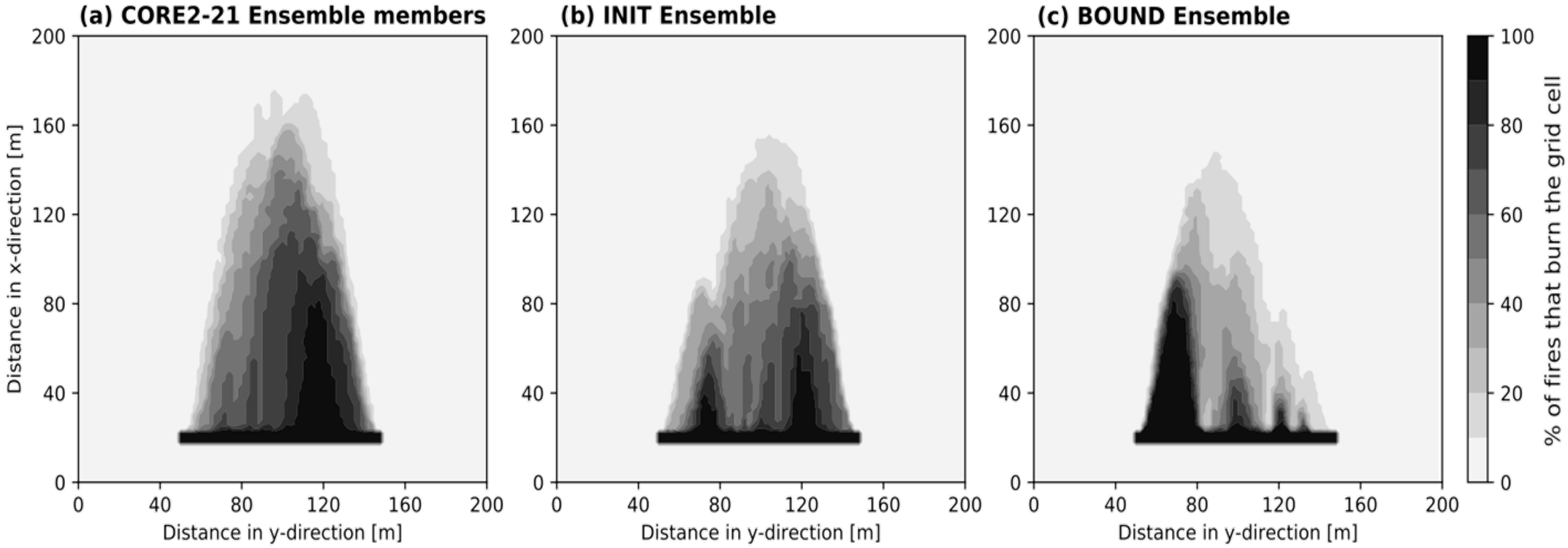


3. Examine fire outcomes:

Impacts of wind boundary vs initial conditions



3. Examine fire outcomes:
Impacts of wind boundary vs initial conditions



Jonko et al. (2021) Sensitivity of grass fires burning in marginal conditions to small perturbations in the turbulent wind field. JGR Atmospheres (submitted).

Next, let's consider relationships between multiple parameters:

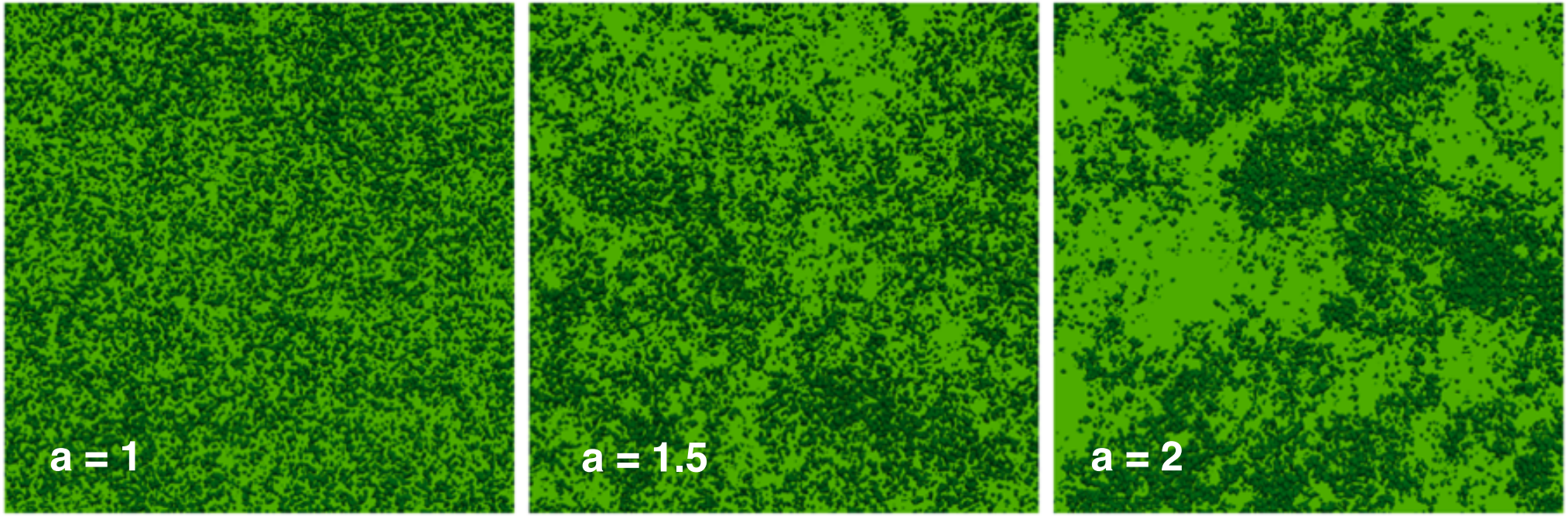
Add in sensitivity to perturbations in fuel initial conditions

Heterogeneous fuel beds – Ponderosa Pine

- **Tree measurements:** Ponderosa Pine stand near Flagstaff, AZ
- **To populate domains:** Simulate 1/f noise process using Inverse Discrete Fourier Transform

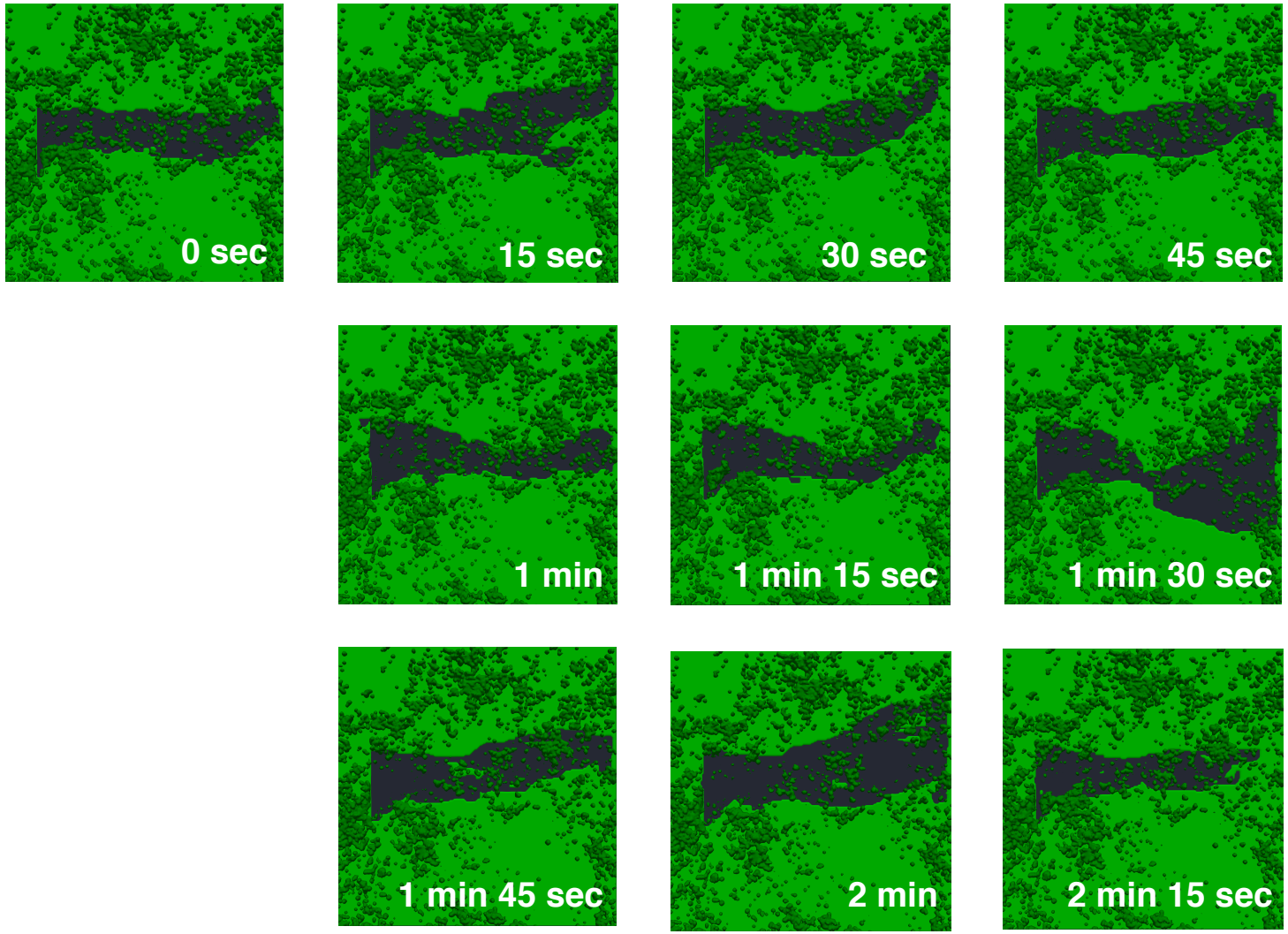
Levels of fuel aggregation

- Continuous surfaces with power spectral density $S(f) \sim 1/f^a$
- a = 0 → white noise, uncorrelated distribution of trees
- a = 2 → Brownian noise, very autocorrelated surface



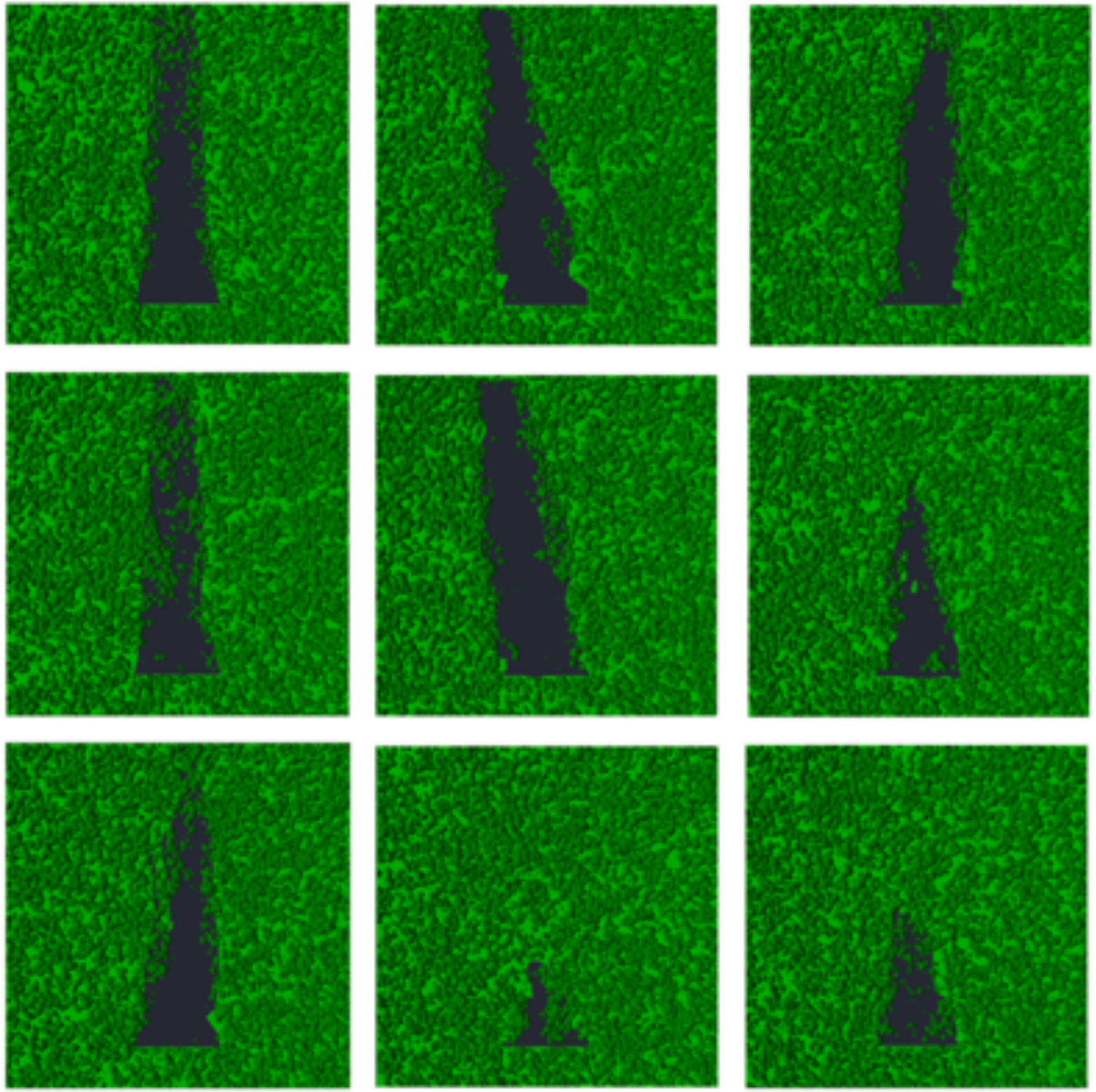
Isolate impacts of turbulence in complex fuels:

Stagger ignitions in time



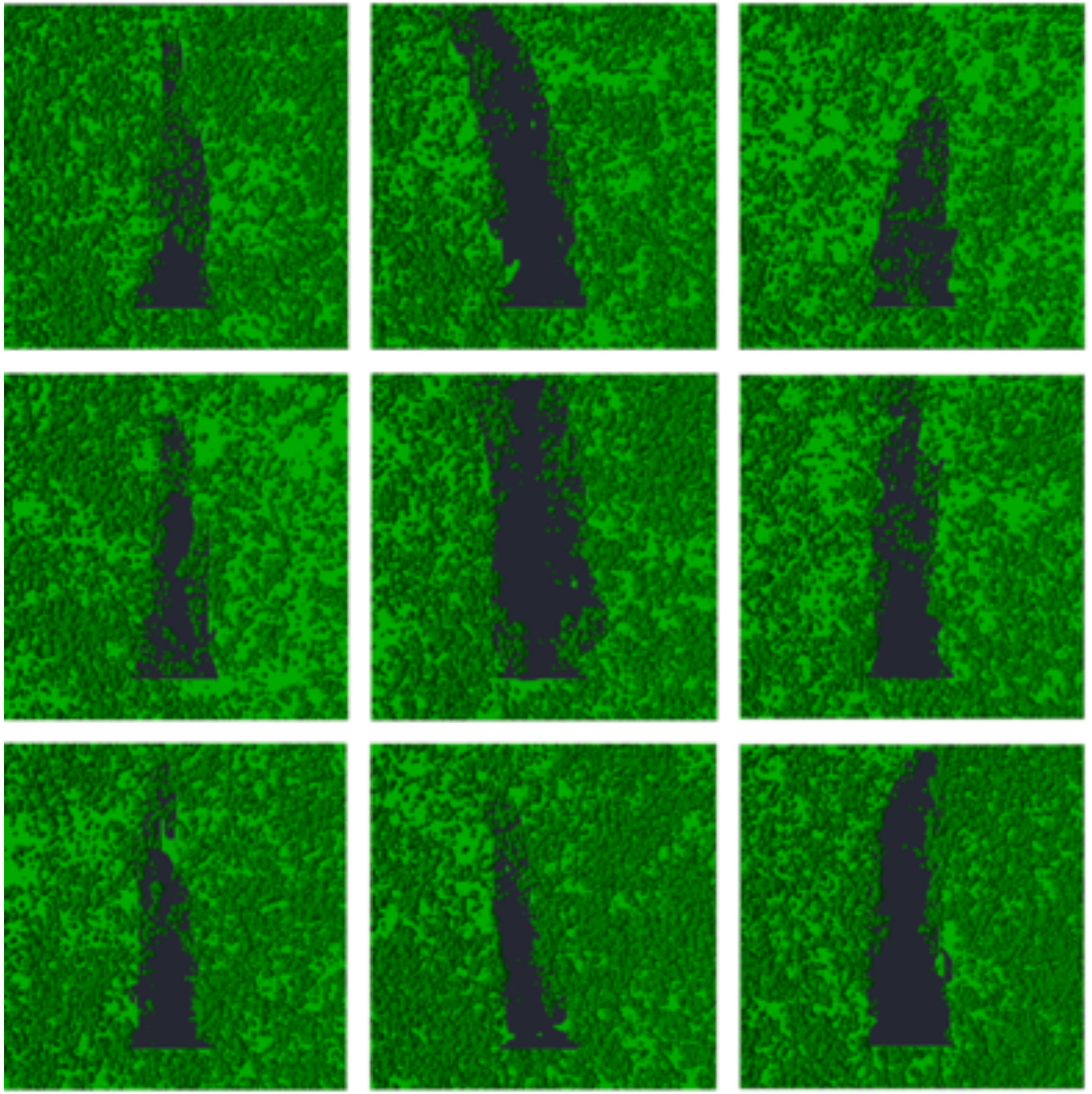
Consider effects of fuels and atmosphere:

Low fuel aggregation



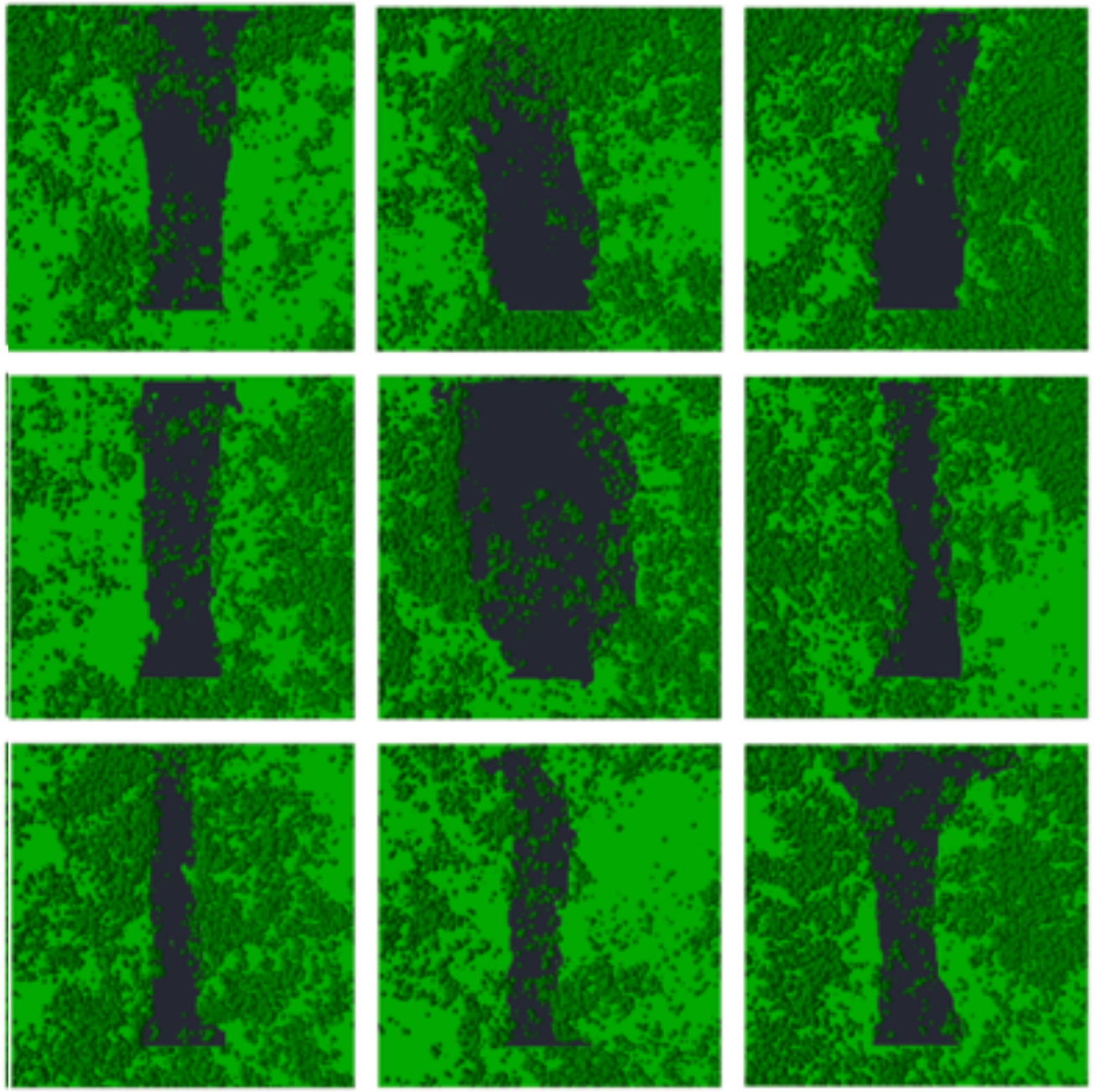
Consider effects of fuels and atmosphere:

Moderate fuel aggregation

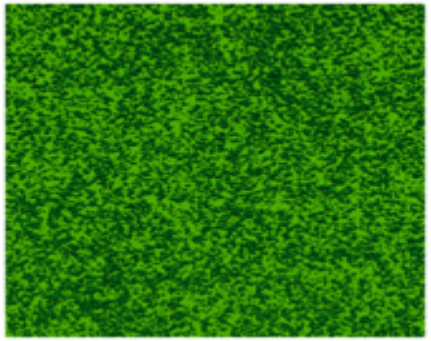


Consider effects of fuels and atmosphere:

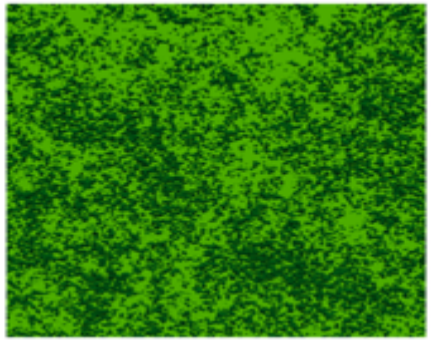
High fuel aggregation



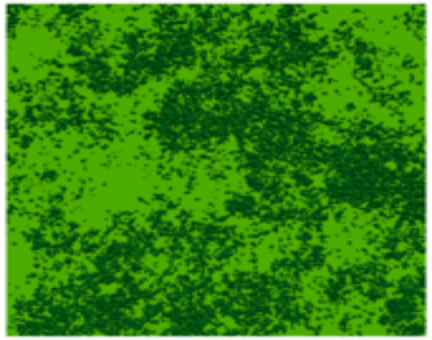
Overview of some first results



	area burned:	surface fuels consumed:	canopy fuels consumed:
average	19432 m^2 (12%)	3015 kg (6%)	7349 kg (4%)
coefficient of variation	0.43	0.44	0.54



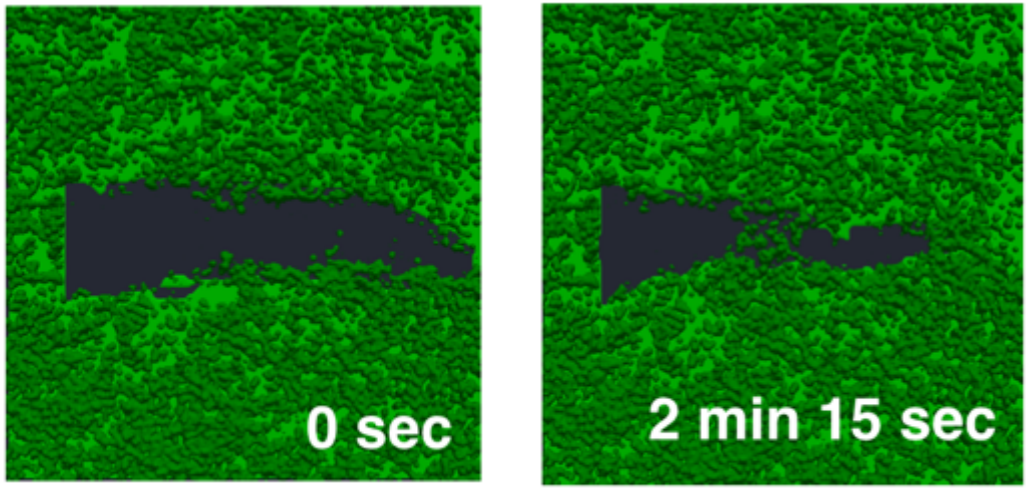
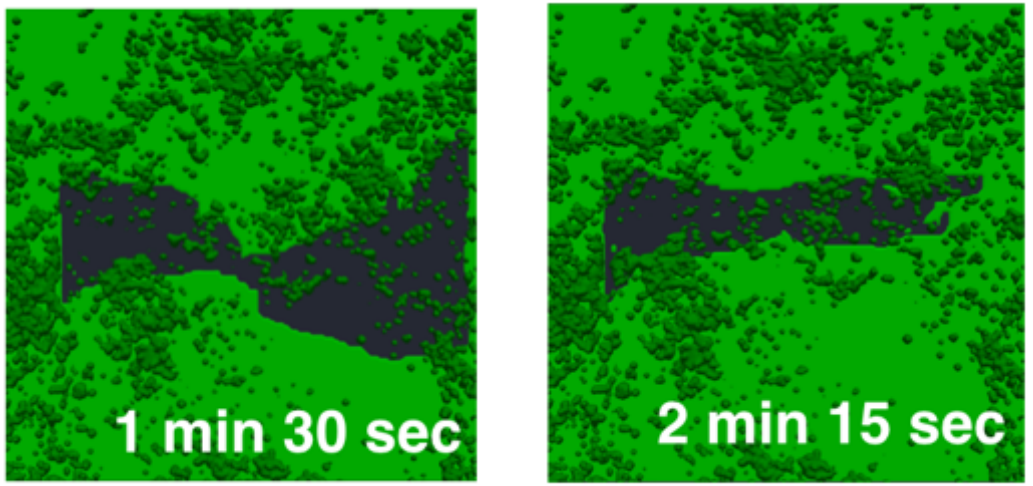
average	22851 m^2 (14%)	3600 kg (8%)	8046 kg (4%)
coefficient of variation	0.35	0.36	0.53



average	32968 m^2 (21%)	5334 kg (11%)	10781 kg (6%)
coefficient of variation	0.40	0.41	0.85

Back to chaos: transitions between sub-critical and critical states

Example of variable surface to crown fire transition



Example of transition between rapid growth and extinction